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ACCESSIBILITY AND PUBLIC TRANSPORT IN SHEFFIELD :
CASE STUDIES OF POLICY IMPLEMENTATION

Helen Mary Workman B.Sc.(Birmingham), M.A. (Sheffield)

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H.M. Workman

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ACCESSIBILITY AND PUBLIC TRANSPORT IN SHEFFIELD :
CASE STUDIES OF POLICY IMPLEMENTATION

Abstract

The planning policies of South Yorkshire County Council are based on the philosophy of helping the "have-nots". From these policies a number of hypotheses concerning accessibility to and by public transport have been defined and tested in the Sheffield study area to gauge the extent to which the policies have been implemented.

The literature on accessibility is reviewed with attention to recent work concerning accessibility by public transport. The Sheffield study area is described and the Structure Plan and other planning documents of South Yorkshire County Council are assessed with regard to policies relating to accessibility and public transport. Recent changes in the level of bus service provision in the study area are summarised.

Access to bus services is investigated in terms of walking and waiting times for 170 sampling points. Overall the route density - service frequency trade-off is found to be optimal. The spatial variation in the walking and waiting times is such that areas with high proportions of people dependent on public

transport do not have more accessible bus services than other areas. Access to bus services is investigated further in the Mosborough area with the relationship between the introduction and improvement of bus services and the occupation of new housing being studied.

Accessibility by public transport to specific facilities is investigated. In spite of Structure Plan policies little improvement in the accessibility of five district shopping centres in Sheffield has taken place. Areas with poor access by bus to sports centres and public libraries are defined and possible locations for new facilities evaluated.

In the first ten years of its existence South Yorkshire County Council has supported policies relating to improvements in accessibility and public transport. The work reported in this thesis indicates that the implementation of such policies has not always been achieved.

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CHAPTER 1

INTRODUCTION

1. Scope of the thesis

The key elements of the title of this thesis - "accessibility", "public transport", "Sheffield", and "policy implementation" - provide an indication of the overall scope of the thesis. It is necessary to discuss the role of each of these key elements at the outset in order to summarise the most important aspects of the work which is reported in this thesis.

(i) Accessibility

A main concern of the thesis is to develop a range of accessibility measures with special reference to bus service provision. Many definitions of the term "accessibility" are discussed in the Literature Review (Chapter 2), but throughout the thesis accessibility is used to denote the ease with which activities or facilities may be reached from given locations using the public transport system. Because a transport system must enable people to reach those facilities which they wish to use accessibility is a very important concept.

Much of the recent work on accessibility has been concerned with rural areas. For example, Moseley (1979) has summarised the work carried out into rural accessibility at the University of

East Anglia in a book entitled Accessibility : the rural challenge. However, accessibility is also relevant in an urban context as has been shown particularly by the work of Hillman et al (1973, 1976). The relevance of accessibility in an urban context is also demonstrated by the policies of South Yorkshire County Council which are discussed in Chapter 4. This thesis is based on the belief that accessibility is not only a rural challenge but also an urban challenge if all citizens are to be able to enjoy the facilities of the city.

(ii) Public transport

In Sheffield public transport is very largely provided by the bus service : from a survey undertaken in 1981 in Sheffield and Rotherham Hay (unpublished) found that 24% of all trips weighted by household type were made by bus, whilst only 0.3% were made by rail and 0.2% by taxi (with 44% being made by car and 28% by walking and cycling). For this reason the terms "public transport" and "bus" are used synonymously throughout the thesis. Unlike the private car, public transport is available to all, except to the severely disabled, and in Sheffield the exceptionally low fares together with the concessionary schemes ensure that the public transport system is affordable by all. Thus any study which is concerned with equity, or fairness, of access for the population as a whole must necessarily be focused on public transport.

In relation to public transport, accessibility is a two-edge concept : accessibility by the public transport network and accessibility to the network itself must be differentiated. In this thesis accessibility by public transport to various facilities is investigated. If the public transport network is to provide access to facilities it must itself be accessible, and the accessibility of the public transport network of Sheffield in terms of walking and waiting times is also studied.

(iii) Sheffield

The study area as defined for much of the thesis corresponds to the built-up area of the City of Sheffield. The case studies were located in Sheffield for practical reasons. Background information on Sheffield and its surrounding region is provided in Chapter 3.

The City of Sheffield is one of the four Metropolitan Districts which comprise the Metropolitan County of South Yorkshire, the County Council being the tier of local government responsible for the provision of public transport services and for strategic planning.

(iv) Policy implementation

The policies of South Yorkshire County Council regarding the provision of accessibility and public transport are stated in the Structure Plan documents and these policies are discussed in

Chapter 4 of this thesis. From this discussion hypotheses have been formulated and accessibility measures developed in order to assess whether policies regarding accessibility by public transport have in fact been implemented. It should be noted that although South Yorkshire County Council is widely known for its low fares policy, this is only one element in a comprehensive set of policies relating to accessibility and public transport.

The research reported in this thesis concerns various case studies of the implementation of policies relating to accessibility. It is not concerned with assessing whether such policies have had the anticipated effects in terms of individual travel behaviour. Furthermore, it should be noted that failure to achieve what was intended through the implementation of accessibility policies may reflect inertia or countervailing forces which negated the work done to achieve the policy. Hence the studies undertaken here are concerned with assessing the attempts made to implement policies relating to accessibility as stated in the South Yorkshire Structure Plan. Other criteria for successful policy implementation such as the satisfaction of expectations aroused by the policy and the use of appropriately designed and cost effective methods of implementation (Lewis, 1984) are not considered.

The research thus has a dual focus. Firstly the development of a family of time-based accessibility measures is undertaken and secondly these measures are used as a basis for the assessment of the implementation of policies relating to public transport provision in Sheffield. Much of the data required for the accessibility measures has been derived from bus timetables and route maps, with the Census and electoral registers providing additional data. (It should be noted that published bus timetables rather than operators' timetables have been used throughout the thesis.) Because this research is concerned with the implementation of policy rather than with the effects of policy implementation on travel, it was not necessary to investigate the impact of policy on individual travel behaviour. Thus there was no need to use research methods such as interviews, questionnaires or surveys and because the work for this thesis was carried out on a part-time basis and without external funding it would not have been feasible to use such methods.

The research consists of a number of case studies related by the common theme of the implementation of policies concerning accessibility by public transport in Sheffield. This case study approach was decided upon because of the constraints imposed by carrying out research on a part-time basis. The research was carried out over the period 1980-84 and for each case study the data used was the most up-to-date available at the time of

undertaking the study. The case studies thus have different cut-off dates. Also it should be noted that although the thesis was conceived as a whole, the research for the case studies was not carried out in the order in which the studies have been presented in the thesis (Appendix 1.1).

Thus having decided that the overall focus for the thesis should be on the development of accessibility measures and their application to the bus network of Sheffield, the choice of case studies and the methods by which they were investigated were influenced by the limited resources, in terms of both time and money, available for the research.

2. Overview of the case studies

In this section a brief summary of the case studies described in later chapters is presented. As already mentioned, the literature on accessibility is reviewed in Chapter 2, in Chapter 3 background information on the Sheffield study area and on South Yorkshire is presented and in Chapter 4 the policies of South Yorkshire County Council regarding public transport and accessibility are discussed. In Chapter 5 a review of the changes which have occurred in the public transport network of Sheffield in recent years is undertaken and such changes are related to Structure Plan policies discussed in the previous chapter, thus enabling an assessment to be made of the overall level of implementation of policies relating to accessibility by public transport.

Chapters 6 and 7 are concerned with the accessibility of the public transport network itself, in terms of average walking and waiting times. In Chapter 6 a simple bus network model is developed in order to explain the pattern of walking and waiting times of the Sheffield data. The model is also used normatively to enable an assessment to be made of the optimality of the route density - service frequency trade-off in Sheffield. In Chapter 7 the spatial variation of the walking and waiting times for the Sheffield study area is investigated and attempts are made to explain this variation by reference to such factors as the level of car ownership and the proportion of the elderly in the population. If South Yorkshire County Council's basic Structure Plan goal of helping the "have-nots" has been achieved, then areas with low car ownership levels and high proportions of elderly people would be expected to have better access to bus services, in terms of lower walking and waiting time, than other areas.

In Chapter 8 the introduction and improvement of bus services in the Mosbosrough area, 10km SE of Sheffield city centre, is studied in relation to the rapid residential development of this area. The objective of this study is to assess whether Structure Plan Policy T2 has been successfully implemented. Access to bus services in Mosborough is compared with that in High Green, 10km N of Sheffield city centre, where residential development has been much less rapid in recent years.

The following three chapters are concerned with access by public transport to specific facilities. In Chapter 9 the accessibility of five district shopping centres in Sheffield is assessed with particular emphasis being placed on recent improvements in bus services passing through these centres. The research is designed to test the implementation of Structure Plan Policy S2. The accessibility of indoor sports centres in Sheffield is studied in Chapter 10. The policies contained in the Structure Plan seek not only to improve access by public transport to existing centres but also to ensure that new centres are situated in locations with good public transport accessibility. Both these aspects are investigated in Chapter 10. In Chapter 11 the accessibility of branch libraries in Sheffield is investigated. Although libraries are not specifically mentioned in the Structure Plan policies, they were selected as an example of a local level facility and thus in Chapter 11 an attempt is made to assess the performance of the public transport network in providing access to local facilities.

Chapter 12 provides a critique of the methodology used in the thesis with particular reference to the accessibility measures and Chapter 13 contains a summary of the research undertaken together with concluding remarks.

3. Other research of particular relevance

Much of the research into accessibility and the associated literature is reviewed in Chapter 2. Here mention is made of research projects which are of particular relevance to the research reported in this thesis. Because of the positive policies adopted by South Yorkshire County Council with regard to public transport provision, South Yorkshire has been the setting for several major studies concerning travel attitudes and behaviour.

Goodwin et al (1983) undertook a survey in South Yorkshire into the effects of the policy of using subsidy to hold down public transport fares and maintain services. An assessment was made of social and travel changes brought about by the public transport policy in South Yorkshire and an analysis of marketing opportunities for public transport was also undertaken. Particular attention was paid to households' attitudes towards public transport provision. In addition to the main report, other articles of interest have been published, for example by Donnison (1983) who discusses the relationships between car ownership, licence-holding and public transport availability.

Hay (1986) has investigated changes in the travel patterns of households in Sheffield and Rotherham by comparing survey data collected in 1981 with that collected in 1972. A comparison with travel patterns of households in areas of Manchester was also undertaken. The objective of this research was to assess the effect of public transport subsidy in terms of its impact on actual travel behaviour.

The Manpower Services Commission has sponsored a study of the role of public transport in the search for employment. In particular the effect of the cheap bus fares in South Yorkshire is assessed by comparing the job searching behaviour of unemployed people in a suburb of Sheffield with that of a Leeds suburb (Bartholomew and Hedges, forthcoming).

A specialised study of the use of buses in Sheffield by elderly and handicapped people was undertaken by Oxley and Benwell (1983). In particular the advantages of the 'split step' entry buses and buses that can be knelt to ease access were investigated.

Thus other recent research has been concerned with public transport in Sheffield and South Yorkshire. These studies have been largely concerned with the assessment of the attitudes of individuals to public transport provision and with the analysis of individual travel behaviour. These approaches are complementary to the approach adopted in this thesis which is concerned with the development of measures to assess levels of accessibility provided by the bus network of Sheffield in relation to the policies of South Yorkshire County Council.

Appendix 1.1 List of case studies in order of completion

Topic	Chapter	Date
Accessibility of district shopping centres by public transport	9	February 1981
The role of public transport in assisting residential development at Mosborough	8	November 1981
Accessibility of sports centres by public transport	10	April 1982
An analysis of recent changes in public transport provision in Sheffield	5	May 1982
Accessibility of libraries by public transport	11	November 1982
Access to bus services in Sheffield : models of the walk and wait elements	6	November 1983
Access to bus services in Sheffield : spatial variation in the walk and wait elements	7	February 1984

CHAPTER 2

THE CONCEPT AND MEASUREMENT OF ACCESSIBILITY :

A REVIEW OF THE LITERATURE

1. Introduction

Accessibility by public transport in an urban environment provides the theme linking the research topics comprising this thesis. It is therefore necessary to review the very large and diverse literature concerning accessibility, paying special attention to accessibility as a product of public transport, in order to place the present study in context. It should be noted that literature relevant to specific topics of the thesis is discussed in the appropriate chapters; the aim of this chapter is to review the more general literature relating to the concept of accessibility and its measurement. The review covers material published up to the end of 1983.

Jones (1981) has produced a useful literature review on accessibility, its definition, measurement and applications. The 73 references cited in this chapter provide some indication of the scope of the literature up to 1983.

2. Definition of accessibility

The concept of accessibility is difficult to define : "There is no generally accepted operational definition of 'accessibility'. Explicit verbal definitions, where provided are often vague" (Nutley, 1979), "There is no universal agreement about the exact meaning of the word 'accessibility'" (Jones, 1982) and "Accessibility is not easy to define in unambiguous and quantifiable terms" (Vickerman, 1974). However, in this thesis accessibility is regarded as a "measure of spatial separation of human activities" (Sherman et al, 1974) and "essentially it denotes the ease with which activities may be reached from a given location using a particular transportation system" (Morris et al, 1979). Thus according to Davidson (1977) a powerful aspect of the accessibility concept relates to the combination of both land use and transportation system characteristics.

Different emphasis can be placed on the various components of accessibility, for as Richardson and Young (1982) point out the concept of accessibility "has been variously interpreted as being the 'nearness to places', the 'nearness to activities' and more recently 'the ease of participating in activities'". Ingram (1971) defines accessibility in terms of 'nearness to places' as "the inherent characteristic (or advantage) of a place with respect to overcoming some form of spatially operating source of friction (for example, time and/or distance)". Zakaria (1974)

Thus it would appear that in recent years the notion of individual accessibility has become of increasing importance. However, the accessibility of an individual is constrained by the available transport system and by the location of facilities. In this thesis attention is focused on measuring the levels of accessibility provided by public transport services in Sheffield. How people will react to these levels of accessibility will depend on individual attributes such as those listed by Whitelegg and such behavioural studies are beyond the scope of this thesis.

The concept of accessibility is therefore concerned both with the location of facilities and with the transport system which allows the individual to reach those facilities he wishes to use. An important issue is whether accessibility should relate simply to the ease with which the nearest facility of a given type (e.g. Post Office, G.P., sports centre) can be reached or whether an element of choice should be introduced into the measure of accessibility. Whilst it can be argued that the availability of a choice of facilities improves the 'quality of life' and should therefore be incorporated into accessibility measures, the notion of choice must be carefully handled if meaningful results are to be produced. Some methods by which the notion of choice has been introduced into accessibility measures are described in the following section.

states that accessibility "denotes the ease with which any land-use activity can be reached from any particular location utilizing a given transportation system" and this definition corresponds to the above 'nearness to activities' notion. The idea of accessibility as 'the ease of participating in activities' is best illustrated by the use of space-time budgets (for example, Anderson, 1971 and Lenntorp, 1976) and is more concerned with personal accessibility (where the unit of study is the individual) rather than with locational accessibility, this distinction being made by Banister (1983).

The notion of personal accessibility can be linked to that of effective accessibility. Knox (1982) describes this as follows : "Since most people's daily lives follow a variety of closely constrained and well-worn paths through time and space, it follows that effective accessibility to particular locations will depend not only on their physical proximity but also on whether they are free to make the journey in the first place" (p.184). Economic access has been described by Rosenberg (1983) as "the ability to purchase goods or services at a specific location" and in the case of North America he points out that without economic access to health care the issue of physical access becomes irrelevant. Summing up these viewpoints, Whitelegg (1982) states that accessibility is "a function of individual attributes such as wealth, income, scope for discretionary travel, commitments to other members of the family or group, commitments to be at a particular place and time and so on" (p.54).

3. Measurement of accessibility

The previous section outlined the variety of definitions of accessibility. The differences in these definitions are reflected, not surprisingly, in the diversity of methods for quantifying the concept of accessibility. "Accessibility measures are based on the premise that space constrains the number of opportunities available. Beyond this point, definitions of the concept differ widely" (Morris et al, 1979). Indeed Jones (1982) states "almost as many ways of measuring accessibility have been suggested as papers written on the subject". Mitchell and Town (1977) state that "a measure of accessibility must show how well the transport and land-use planning system operate in allowing people to reach the destinations they require for particular purposes". Weibull (1976) has postulated certain general requirements for accessibility measures and these have been stated as six axioms and their mathematical form derived.

One factor which influences the way in which accessibility is measured relates to the use which is to be made of that measure. If it is to be used as a variable for some larger model, for example of trip generation (see Leake and Huzayyin, 1979), then a relatively simple measure may be acceptable. If the objective is to study accessibility per se then more complex and detailed measures will be required. This distinction should be borne in mind in the following discussion of various types of accessibility measures.

Richardson and Young (1982) have classified accessibility measures into 6 types, namely topological, relative, integral place-accessibility, cumulative-opportunities index, gravity-type measure and logsum term. A further category, namely space-time budget, can also be distinguished. The characteristics of measures in each group are discussed below with particular attention being paid to their potential usefulness in relation to measuring the accessibility conferred by public transport on residents in urban areas.

i) Topological

These measures depend for their theoretical basis on graph theory and the transport network is reduced to a graph consisting of vertices and edges representing the linkages and nodes of the network. In particular the connectivity matrix which is based on the presence or absence of direct links between nodes is important. Various indices, such as the Shimbél index and the cyclomatic number, have also been devised to describe overall levels of "connectedness" of the transport network and its nodes. The classic paper in this field is that by Garrison (1960) concerning the structure of the U.S. Interstate Highway system. An example of the use of topological measures in an urban context is provided by Taylor (1976) in his study of the tramway network of Poznań city in Poland. Muraco (1972) has also used this approach to delineate accessibility surfaces for Indianapolis and Columbus, Ohio.

Topological accessibility measures relate to the ease of movement permitted by the transport system. The fact that no regard is paid to the location of activities or opportunities is a major weakness of this approach to the measurement of accessibility.

ii) Relative

The relative index of accessibility was stated by Ingram (1971) as :

$$A_{ij} = d_{ij}$$

where A_{ij} = the accessibility of zone i relative to zone j
 d_{ij} = the straight line distance between zone i and zone j.

Relative accessibility indices measure accessibility simply in terms of the ease of movement, in this case denoted by straight line distance, between two zones.

A similar approach is provided by the route factor method, although this method is not specifically listed by Richardson and Young. A route factor is defined as the ratio of the route distance to the geodetic distance between two points on a network. The advantage of this method of measuring relative accessibility is that it provides a measure which separates the effect of the structure of the network from the effect of the relative location of the two points. Timbers (1967) used route factors in a study of the road network of the United Kingdom.

iii) Integral place-accessibility

An integral accessibility index is stated by Ingram (1971) as :

$$A_i = \frac{\sum_{j=1}^n d_{ij}}{n}$$

where A_i = the accessibility of zone i
 d_{ij} = the straight line distance between zone i and zone j
 n = the number of zones.

Baxter and Lenzi (1975) utilized this type of accessibility measure in order to model the road network of Reading. As a result of their work they "support the adoption of distance measurements of accessibility based on abstract patterns broken by the major geographical constraints, rather than on elaborate digitization of the real distributor network". Kirby (1976) has sought to extend this work to give results for a variety of homogeneous grid networks.

As with the topological accessibility measures discussed in Section 3(i), this type of index relates simply to the ease of movement between zones, with no account being taken of whether a zone is particularly attractive in terms of its land-use

activities and therefore likely to be a focus for travel. It would be possible to replace the straight line distance between zones with a figure representing the quality of the public transport service between each pair of zones. However, the resulting accessibility index would not be particularly meaningful in view of the fact that the relative location of activities or opportunities is ignored.

iv) Cumulative-opportunities index

These measures index the accessibility of various opportunities according to the number which can be reached from the origin of interest within specified travel distances or time. The method does not discount measures of opportunity over distance and an obvious weakness is the arbitrary selection of the isochrone (or isodistant) of interest. According to Morris et al (1979) a major disadvantage of these measures when presented in graphical form is that a single value of accessibility is not produced. However, Black and Conroy (1977) overcome this potential problem by integrating to find the area under the cumulative-opportunities curve and using the result as an index of accessibility.

Wachs and Kumagi (1973) have studied accessibility to various job categories in the Los Angeles region using a cumulative opportunities approach. The index used for each zone is as follows :

$$AI(T)_i = \frac{1}{100} \sum_{j=1}^J \sum_{k=1}^K P_{ijk} E(T)_{ijk}$$

where $AI(T)_i$ = accessibility index for zone i using a travel
 time radius of T minutes
 j = income category, $j = 1, 2, 3 \dots J$
 k = occupation category or job class, $k =$
 $1, 2, 3 \dots K$
 P_{ijk} = proportion of work force of zone i which is in
 income category j and occupation category k
 $E(T)_{ijk}$ = employment opportunities (in hundreds) in
 income category j and occupation category k
 within T minutes of travel from zone i
 $1/100$ = a scaling factor.

Using a similar method they carried out an analysis of physical
 accessibility to health care services. The main conclusion was
 the striking difference in the number of health care facilities
 which could be reached within 30 minutes travel time by car
 compared to transit; for the Bell Garden zone, it was possible to
 reach only 1 hospital and 36 G.P.s by transit but 149 hospitals
 and clinics and 1529 G.P.s by car.

Dasgupta (1982a, 1982b) has carried out a travel-to-work
 survey of 3000 employed adults in one inner and two outer areas
 of Greater Manchester. He found that whereas a 30 minute car
 journey provided access to job opportunities located over wide
 areas, access to jobs for bus users was restricted to small areas
 because of limited route and destination choice.

v) Gravity-type measure

The measures in this category consist of a variable relating to the attractiveness or potential of the destination zone and a variable relating to the effort required in overcoming the distance separating the origin and destination zones. The first use of this type of model in measuring accessibility is attributed to Hansen (1959). Leake and Huzayyin (1979) give the general formulation of this measure as :

$$A_i = \sum_{j=1}^n S_j f(t_{ij})$$

where A_i = the measure of accessibility of zone i to activities located within the remaining zones of the area

S_j = the size of activity in zone j, such as the number of jobs, population, etc.

$f(t_{ij})$ = a travel resistance function describing the effect of the travel time or distance between zones in the area, or the interaction between them (e.g. $f(t_{ij}) = 1/t_{ij}^\alpha$ or $= e^{-\alpha t_{ij}}$, where α is a constant and e is the exponential constant)

n = the number of zones in the area.

Zakaria (1974) discusses various formulations of accessibility measures based on the gravity model.

Leonardi (1981) has extended the concept of the attractiveness of the facility to take into account sensitivity of demand to accessibility and congestion by assuming that demand for activities increases with accessibility and that the more a facility is crowded, the less attractive it will be for customers. Fotheringham (1983a,1983b) has also investigated the effect of competition and agglomeration on destination choice and he states that "gravity models are misspecified when they do not explicitly model the relationship between interaction and the accessibility of a destination to all other destinations" (1983a).

Gravity measures have formed the basis of many accessibility studies. For example, Martin and Dalvi (1976) investigated accessibility by private and public transport in London and their work is particularly noteworthy in that they studied the sensitivity of the accessibility model to the choice of attractiveness variables, the parameter values of the travel cost function and the type of zoning system adopted (Dalvi and Martin, 1976). This work was used by Pike and Vougioukas (1982) in the construction of a public transport accessibility model for Camden.

vi) Logsum term

Richardson and Young (1982) state that "As the gravity model of trip distribution can yield a measure of accessibility, so too the more recently developed logit model can also yield a measure of accessibility". This measure of accessibility of a site is given by :

$$A_i = \ln \sum_{k=1}^m e^{c(B_k - C_{ik})}$$

where B_k = benefits obtained from activity participation at site k

C_{ik} = cost of travel between i and k

c = sensitivity coefficient

m = total number of alternatives.

This "logsum" term represents the expected value of the maximum utility to be gained in such a destination choice situation. Koenig (1975) has developed a similar utility index and he sees one advantage of this approach being in its avoidance of travel time used in conventional accessibility indices which, he feels, may underestimate the movement handicap of people forced to use an inadequate public transport system.

Richardson and Young (1982) provide a summary of existing accessibility measures discussed so far. This is reproduced in Table 2.1. They state that these measures "have shown a steady

Table 2.1 Summary of existing accessibility measures

Accessibility Measure	Features
Topological	Specifies whether two sites are connected
Relative	Measures degree of connection between two sites
Integral place-accessibility	Measures degree of connection between one site and all other sites
Cumulative-opportunities index	Measures number of activities accessible within specified travel cost
Gravity-type measure	Measures accessibility to all activities in terms of the ratio of activity opportunities to travel cost
Logsum term	Measures accessibility to all activities in terms of difference between activity benefits and travel costs

Source : Richardson and Young (1982)

progression in their degree of complexity and behavioural veracity". Similarly, Pirie (1979) concludes from his review of accessibility measures that "Gradually a series of incremental improvements have been made to the distance, topological, gravity and cumulative-opportunity measures of accessibility. These have mainly taken the form of disaggregation". These improvements have in many cases been made possible through the increasing availability of computing facilities. The ability of computers to handle large amounts of data has lessened the importance of simple measures of accessibility such as the topological measures whose original appeal lay in the simplification of complex networks to forms which could be more easily handled. The effect of computing facilities on the measurement of accessibility is discussed further in Section 4.

vii) Space-time budget

The move towards disaggregation and concern over the behavioural veracity of accessibility measures mentioned by Pirie (1979) and Richardson and Young (1982) is expressed most clearly in a final category of measures, namely space-time budgets. The method is based on the determination of periods when an individual has to be at certain locations and the remaining periods are then studied in terms of the opportunities available for a specified transport mode. In this second stage the accessibility measures used may be taken from categories of

measures already discussed; it is the introduction of the time dimension and the focus on the individual which justify the delineation of space-time budgets as a separate category of accessibility measures.

A recent example of research using this method is that carried out by Forer and Kivell (1981) who investigated access to urban facilities for housewives without cars in Christchurch, New Zealand. They concluded that "although little absolute deprivation of access to facilities exists the costs of access in time and opportunity vary greatly".

4. Problems in measuring accessibility

Some of the problems encountered when measuring accessibility have already been mentioned in the context of the groups of measures outlined above. However, it is necessary to discuss some further problems. The use of zones for grouping origins and destinations is common to many accessibility measures and these measures can be criticised on account of the arbitrariness of the zone size and configuration. However, Savigear (1967) provides some guidelines in this context, for example advising that land-use within zones must be considered when drawing boundaries.

The increasing use made of disaggregated measures of accessibility has already been mentioned. This can cause problems concerning data collection and manipulation, for as Pirie (1979) states "the difficulty and expense of collecting detailed data means that the selection between the conceptually superior but data-hungry disaggregate measures and the aggregate measures must be made with a clear understanding of the intended application of the measures". Bach (1981) highlights a further problem : "increased spatial disaggregation will lead to increasing - possibly unsurmountable - difficulties in measuring and calculating spatial distances that are appropriate to the level of disaggregation".

Even when disaggregated data are used, there remain two classes of assumptions hidden in accessibility measures according to Pirie (1979) and these relate to the destinations and to the origins of measurements. The problem regarding destinations is highlighted in the dialogue between McLafferty (1982,1983) and Kirby (1983). In criticising McLafferty's original paper, Kirby states that it must be made clear which services are being evaluated, for example a children's play area or a large leisure complex and he proposes an access-opportunity measure in which the size of the facility (in terms of employee hours) is taken as a measure of its attraction. McLafferty then questions the assumption that larger service facilities are more attractive than smaller ones.

In many accessibility studies, single origins are used in accessibility measures and are usually taken to be home-based. However, Richardson and Young (1982) have extended the concept of accessibility to account for the occurrence of linked trips and "a simple numerical comparison between an unlinked-trip accessibility measure and the linked-trip accessibility measure has shown that the unlinked-trip measure underestimates the accessibility of non-central locations". Bentley et al (1977) have also studied activity linkages of intra-urban journeys through travel diary data using a space-time budget framework.

Another problem associated with the measurement of accessibility relates to its multidimensional nature and more particularly to the choice of units of measurement. In overcoming distance whatever the transport mode used the generalised cost involved comprises elements of time, energy and money. Different cost elements are more important in certain phases of a journey than others, and this is particularly the case with public transport journeys which comprise four stages : 1) the walk to the bus stop, expending time and energy, 2) the wait for the bus, involving time only, 3) the bus journey itself, which can be costed in terms of travel time and fare, and 4) the walk from the bus stop to the destination, again involving time and energy. In most measures of accessibility these costs are reduced to one unit of measurement, minutes or £s, in order to achieve a single accessibility value, rather than being accepted as separate, non-additive quantities. The reduction to one unit of measurement necessarily involves arbitrary decisions.

The value of time expended on various stages of a journey is often weighted in an attempt to reflect the value people place on their time when walking, waiting or travelling in a vehicle, for according to Jennings and Sharp (1976) "people apparently dislike waiting for a bus or train or walking, more than they dislike travelling time spent in a car or bus". In many studies the generalised costs of walking time and waiting time are taken to be equal at twice the cost of a unit riding time (Department of Transport, 1980). Whilst such weightings may have some behavioural validity, the accessibility measure no longer reflects actual travel times. An example of the weighting of travel time components is found in the model by Pike and Vougioukas (1982) which is discussed in more detail in Section 6.

A further problem in measuring accessibility concerns whether the measure should reflect observed travel behaviour or whether it should relate rather to potential opportunities. Breheny (1978) believes the latter is more important and therefore criticises many existing accessibility measures : "If accessibility measures are to be used to help improve levels of accessibility and move the system towards a more satisfactory state, it seems illogical to use measures which may have built into them the inefficiencies and inequalities of the existing system". Similarly he objects to accessibility measures which incorporate distance decay functions as the values of these

functions are derived from studies of actual behaviour. Pirie (1979) acknowledges this problem when he states that what is required is a measure of accessibility which is sensitive to adaptive behaviour, "to the fact that accessibility is always created and is not just something to be had by virtue of one's locale".

However, on a more positive note, Cohen and Basner (1972) in their investigation into the possible uses of accessibility as an evaluation criterion for testing alternative transportation systems state that accessibility measures are "easily and practically obtained. The results can be presented to policy boards and interested citizens using a variety of techniques that can be meaningful to the group involved".

5. Importance of accessibility

Polus and Kumove (1979) have investigated the concept and measurement of accessibility as used by specific planning disciplines. They classify accessibility measures into two categories, operational measures and behavioural models, and claim that the "operational measures are most popular among traffic and environmental planners, who are interested in the immediate physical problems of environmental amenity and mobility. The three higher level planning disciplines - transportation, urban

economic and comprehensive urban planning - address themselves to the behavioural aspects of accessibility that operate within the dimensions of time, space and social interaction". They also identify the use of accessibility measures over three time spans; "Within a short time span, an ease-of-movement concept, such as the traffic engineering approach, will usually provide the maximum benefit... The mid-range plan concentrates on the social problem of linking people to various social and economic activities in the urban area... The promise of more permanent satisfaction of accessibility lies with a long-range plan. Only this plan horizon allows a planner freedom to deal with complex problems of optimal location of activities and the conditioning of social attitudes towards travel".

The above quotations provide some indication of the importance of the accessibility concept and of the diversity of uses made of the various accessibility measures. It is now proposed to review in more detail the importance of accessibility in three areas which are particularly relevant to the focus of this thesis and to illustrate these with a selection of examples from the literature. The three areas are concerned with welfare considerations, equity considerations and the relationships between public transport, car availability and accessibility.

i) Welfare considerations

Hillman et al (1973,1976) carried out surveys in five types of area (village, small town, new town, city suburbs and inner London) in order to investigate travel patterns of various categories of people. The findings reveal that the location, scale and population catchment of facilities and the density of residential accommodation influence accessibility and, as a consequence, travel patterns. The importance of walking as a mode of transport is highlighted and the necessity of assessing the travel needs of all members of a household is stressed. Their work has been an important influence on later research into accessibility and this is clearly seen in the context of rural welfare. For example, Moseley's (1979) book Accessibility : the rural challenge summarizes the in-depth research carried out at the University of East Anglia and Nutley's book entitled Transport policy appraisal and personal accessibility in rural Wales, published in 1983, studies in particular the effect of the Government sponsored Rural Transport Experiment (RUTEX). Perhaps this recognition of the importance of the role of accessibility in rural welfare should be extended to urban areas; is accessibility not also an urban challenge?

The significance of the location of facilities was noted by Hillman et al; "evidence shows that the scale and location of facilities and the density of their population catchments

strongly influence accessibility - and the costs to the community of travel to them" (1973). White (1979) describes the location of public service facilities in Manhattan, South Philadelphia and Honolulu using nearest neighbour analysis and quadrat analysis. He finds that "accessibility of public facilities to users cannot be considered the sole criterion governing public facility patterning" mainly because of the importance of functional linkages between service facilities. However, White concludes "it is envisaged that a more comprehensive view of public facility location analysis will enrich rather than restrict the concept of accessibility".

Ambrose (1977) in discussing the issue of service location describes the trade-off between the demands of equity (with an emphasis on small locally-orientated facilities) and the dictates of efficiency. The "efficiency" solution is usually seen in terms of large-scale centralised units of provision but Ambrose feels that these centralising trends might well be regarded as creating highly inefficient provision in terms of the aggregate amount of time and energy necessarily expended in reaching the locations at which essential goods and services are available. Jones and Kirby (1982) urge that public facilities should be examined "not only in the context of how their location has been determined, but also in the context of how their spatial distribution affects the individual".

ii) Equity considerations

The levels of accessibility available to an individual are one set of factors determining the quality of life for that individual. As these levels vary between individuals, the notion of equity must be considered, for as Bach (1981) states any analysis of accessibility and access opportunity "touches upon highly political issues of spatial equity and spatial efficiency". He cautions that even though operational definitions of accessibility and access opportunity may suggest scientific objectivity, "they in fact do no more than hide basic issues of spatial politics". Similarly Studnicki-Gizbert (1982) cautions that "the inherent arbitrariness in developing accessibility criteria must be frankly admitted when dealing with issues of equity, which in the final analysis must rest on the foundations of the socio-philosophical preferences".

Doling (1979) surveys various types of gravity model and cumulative-opportunity accessibility measures and states that "the adoption of such indices could be instrumental in the reformation of transportation objectives, such that instead of seeking to optimize global objectives, the emphasis is placed upon minimizing the system disbenefits to individuals or groups of individuals". Pirie (1981) discusses the possibility and potential of a public policy on accessibility and he states that such a policy will "almost certainly aim at alleviating the

inaccessibility suffered by the carless". However, in a recent controversial paper McLafferty (1982) studies public service location in relation to the spatial structure of urban areas and concludes that in typical Western cities "the spatial constraint implies that the bulk of possible service locations are physically more accessible to low- than to high-income groups".

Studnicki-Gizbert (1982) states that the application of cost effectiveness analysis to the solutions of the problem of accessibility ("if \$ x mil is available to remedy the lack of access, then what and how can the maximum accessibility improvement be obtained by different mixes of public investments in different areas or for different population groups") presupposes (a) the establishment of the desired accessibility standards, and (b) acceptability of interpersonal comparisons. Kaiser et al (1972) have measured accessibility preferences of a sample of U.S. metropolitan households against accessibility standards to elementary schools, shopping centres and work locations laid down by the American Public Health Association and they conclude that "the commonly accepted maximum time distance standards are inadequate measures of people's accessibility desires". However, as Studnicki-Gizbert (1982) points out, any method used to define accessibility standards is "essentially arbitrary" and Popper and Hoel (1976) state that "minimum absolute standards for mobility or accessibility are difficult to justify". On the other hand,

Wickstrom (1971) recommends the development of user-oriented transportation standards : "such standards, expressed in terms of access to urban opportunities, can serve to identify desirable mixes of transportation modes and help identify potential trade-offs between land development and the provision of transportation facilities".

These quotations serve to indicate the potential political applications of the concept of accessibility and to draw attention to the fact that accessibility measures contain assumptions which may be construed as having political, ethical or moral content.

iii) Public transport, car availability and accessibility

Hillman et al (1973) advocate the importance of walking and public transport in providing access because of their universality; "it is only after walking and public transport have been planned for that a role for the private car can be seen". This is very different from the then current methods of assessing transport plans which were seen as being "very directly inegalitarian - giving to those who have, and taking from those who have not". The disparity in the range of facilities accessible to those who have the use of a car and those who do not has already been noted in the context of the cumulative-opportunities index (Wachs and Kumagi, 1973,

Dasgupta, 1982a,1982b). Knox (1978) points out that "in Britain, where levels of car ownership in cities are relatively low but quite variable between neighbourhoods, mode of transport is especially important in determining the accessibility of different groups to urban amenities".

Spatial patterns of accessibility can be studied with reference to car ownership levels. Cooper et al (1979) describe the accessibility analysis undertaken as part of the West Yorkshire Transportation Studies. Two of the main features to emerge concern car availability : there was a "large difference in travel costs (time and money taken together) incurred between people with and without the personal use of a car" and "in larger towns, a marked deterioration in accessibility was evident in housing areas towards the edge of the built-up areas, with local authority developments containing a high proportion of people dependent on public transport exhibiting particular problems in such locations".

Several researchers have attempted to demonstrate that car ownership levels are affected by the quality of public transport accessibility. For example, Button et al (1980,1982) concluded from a study of 7,800 households in West Yorkshire that households living in areas which have good access by public transport to work opportunities tend to both have a lower level of car

ownership and to be less inclined to become car owning. Based on their findings, they suggest that conventional approaches to car ownership forecasting based solely upon household characteristics are inadequate. Goodwin et al (1983) have also made reference to the relationship between car ownership and levels of public transport provision in South Yorkshire. As part of this study, Donnison (1983) investigated licence-holding and car availability. He believes that the main factor explaining low levels of licence-holding among young people is the economic recession; "the young do not have the money to embark on private motoring - lessons and then car ownership - and this is reinforced when people have plenty of time on their hands (time-saving being one of the main attractions of private transport) and - in South Yorkshire's case - when public transport fares are very low".

Dallal (1980) found that residents living in 'high accessibility' areas of the London Borough of Hammersmith and Fulham did not have high levels of car ownership in spite of relatively high incomes and he suggests that "having good access to public transport services may act as a disincentive to running a car". Fairhurst (1975) has also studied the influence of public transport on car ownership in London. He considers 11 factors which influence car ownership and one of these is the attractiveness of public transport relative to the private car. His findings based on data from the 1962 London Transportation Study imply that "policies favourable to one mode will have not only an initial effect on modal split but also significant second order effects as marginal households consider whether to own a car".

However, the findings of such studies are open to alternative interpretation. If households without cars choose to locate in areas which have good public transport services then a negative relationship between car ownership and public transport accessibility will be found. If people living in areas with good public transport decide not to own a car then the same negative relationship will occur. The interpretation problem is thus one of cause and effect. In London in particular factors such as congestion and parking problems may suppress car ownership regardless of the quality of public transport services. Thus although the studies discussed above suggest that car ownership levels are affected by public transport accessibility, the relationship between car ownership and public transport is complex.

6. Public transport accessibility measures

Because the focus of this thesis is on accessibility by public transport, it is necessary to pay special attention to the development and application of accessibility measures relating to public transport.

Leake and Huzayyin (1979,1980) have developed a distance measure of accessibility for public transport and state its general form as follows :

$$B_i = \sum_{m=1}^k \sum_{r=1}^h f_{r.m}^i \cdot l_{r.m}^i \text{ (veh km/h)}$$

where B_i = the public transport accessibility measure for zone i

$f_{r.m}^i$ = the frequency of public transport mode m (veh/h), operating over route r in zone i

$l_{r.m}^i$ = the length of route r (km) for public transport mode m passing through zone i

h = the number of public transport service routes passing through zone i

k = the number of public transport modes serving zone i .

It should be noted that bus frequency was calculated as :

$$f_r^i = \frac{N_r}{T_r} \cdot \lambda_r$$

where N_r = the number of buses operating daily on a weekday on route r

T_r = operation time of the bus service on route r on a weekday (hours) i.e. (last bus departure time - first bus departure time), for the bus service operating on route r

$\lambda_r = \frac{T_r}{T_{\max}} \cdot 100$

T_{\max} = the longest operation time (hours) on a weekday of all bus services in the study area.

The correction factor λ_r was introduced to take into account the effect of the variation in the operating periods of each bus service. A further refinement to this measure was introduced to take into account the variation in the size of zones but attempts to relate the level of accessibility to the size of the areas within walking distance of bus stops within each zone were abandoned because determination demanded assumptions on the values of average walking speed and walking time.

The public transport accessibility model for Camden constructed by Pike and Vougioukas (1982) is outlined below. As already mentioned this model is based on gravity-type accessibility measures and weightings are attached to the various components of travel. The distance function of the gravity model is expressed in terms of the generalised cost of travel which Pike and Vougioukas define as follows :

$$\begin{aligned}
 C_{ij} &= \text{generalised cost of travel from zone } i \text{ to} \\
 &\quad \text{zone } j \text{ in minutes} \\
 &= 2x \text{ walk time (assuming a walking speed of} \\
 &\quad \text{5mph)} \\
 &+ 2x \text{ waiting time } (\frac{1}{2}\bar{h}(1+v^2)), \bar{h} = \text{mean observed} \\
 &\quad \text{headway, } v = \text{coefficient of variation of the} \\
 &\quad \text{observed headway, with a cut off value of 20} \\
 &\quad \text{minutes)} \\
 &+ \text{in-vehicle time} \\
 &+ \text{fare/value of time} \\
 &+ 4x \text{ number of services boarded.}
 \end{aligned}$$

Pike and Vougioukas outline the intended applications of their model : (1) to investigate accessibility to employment, recreation facilities etc, (2) to identify bus routes which perform an important social role, (3) to investigate the potential for new bus routes serving areas of low accessibility, and (4) to assess the transport impact of new development proposals.

An accessibility index relating to the walking and waiting times involved in reaching public transport access points has been developed by Dallal (1980) with objectives very similar to those used in this thesis. Using survey data from a random selection of 1 in 40 households in the London Borough of Hammersmith and Fulham he constructs a contour map for the Borough showing six levels of accessibility to public transport services. The index is based on the combination of walk and wait time such that all public transport services are reduced to notional services with zero walk time (e.g. a walking time of 4 minutes and an average waiting time of 6 minutes is taken as being equivalent in terms of total access time to a regular service right outside the door of 3 vehicles per hour). The methodology and results of the study will be of value in identifying "those geographical areas within the Borough and groups within the community which are most in need of improvements in public transport" and in providing "an objective means of testing the effects of changes in the routing and frequency of public transport services".

Ruppert (1979) reports on a procedure to measure the accessibility of buildings around a public transport stop/station and he outlines the three stages as :

- 1) All target activities around a stop (e.g. workplaces) are totalled, the target activities being reduced to the walking distance acceptance function. (The acceptance functions were determined from a survey of local authority workers in Karlsruhe.)
- 2) The stop accessibility of each stop is calculated. This is done by taking the reduced values of the target activities of the stop in question and adding the target activities of the remaining stops, the latter values are then also reduced according to their distance from the stop in question. This second reduction is determined by the acceptance functions for waiting, travelling and changing times.
- 3) The accessibility values of blocks of buildings in the vicinity of a stop are determined, reduced according to the walking distance between the stop and the block.

It is envisaged that this detailed approach will be applied in "the evaluation of plans for public transport networks, structure plans and the allocation of infrastructure installations".

7. Conclusion

In earlier sections of this review attention was drawn to the problems encountered in defining and measuring accessibility. It is likely that these problems will remain with the concept of accessibility for some time to come. Pirie (1979), for example, states "Notwithstanding the currency and extensive use of the notion of accessibility, there is a fair amount of doubt expressed about our full grasp of the concept" and similarly "Accessibility may be measured in several ways depending on one's conception of it. The ultimate question then is whether conceptions can be wrong or only inappropriate".

Polus and Kumove (1979) state that "the idea of accessibility itself is complex and at times vague. These characteristics - diversity, complexity, vagueness - make it very difficult to formulate a single model or measure" and "without a comprehensive theory of accessibility, there is little purpose in attempting to formulate a comprehensive measure". Pirie, in a later paper (1981), comments that "reflecting on the possibility of formulating and implementing an effective policy on accessibility suggests the importance of giving as much attention to the development of a conceptually robust and incisive notion of accessibility as to the improvement of accessibility measures".

Thus it would appear that although the wide range of accessibility measures and applications which have been discussed here will probably continue to expand, the theoretical underpinning of such work will remain open to criticism and debate.

The literature reviewed in this chapter has been primarily concerned with the description and measurement of accessibility. However, there is a further aspect of accessibility which has not yet been considered and this relates to its geographical variability. The literature concerning the description and explanation of this variability is reviewed in Chapter 7 which is concerned with the spatial variation in access to bus services in Sheffield.

8. The use of accessibility in this thesis

This literature review has provided an indication of the different ways in which the concept of accessibility can be conceived and the consequent variety of associated measures and applications. In summary, the definition which best corresponds with the view of accessibility used throughout this thesis is that due to Morris et al (1979) : "Essentially it denotes the ease with which activities may be reached from a given location using a particular transportation system".

The measures of accessibility which will be used in later chapters of the thesis are outlined now so that they can be placed in the context of the published literature. It should be noted that for practical reasons of data collection the measures of accessibility used here relate to specific geographic locations. Thus whilst being more precise than the zonewide measures used in many studies of place accessibility, they are not "conceptually superior but data-hungry disaggregate measures" described by Pirie (1979).

The subject of Chapters 6 and 7 concerns access to bus services. Here the walking time and waiting time components are investigated. These form the basis of two elements of any public transport accessibility measure, as was seen for example in the Camden accessibility model of Pike and Vougioukas (1982) and in Dallal's (1980) study of accessibility in the London Borough of Hammersmith and Fulham. The walk and wait elements of public transport journeys also provide the focus of Chapter 8, this time in the context of a rapidly developing residential area.

In Chapters 9 to 11 accessibility by public transport to specific facilities, namely district shopping centres, sports centres and libraries, is investigated. The accessibility of shopping centres is studied in terms of measuring the quality of public transport provision based on these centres. This study in

effect seeks to determine the catchment areas of the centres. In the research carried out into the accessibility of sports centres by public transport an accessibility index is developed which more closely resembles some of the conventional measures discussed earlier. The origin zones are formed by the intersections of the 1km National Grid, the destination zones are given by the locations of sports centres and all are assumed to be equally attractive. The effort involved in overcoming the distance separating the origin and destination zones is defined in terms of total travel time. This measure is simpler than that of Pike and Vougioukas (1982) who used scaling factors before adding the component times for each part of the journey. In this study the component times of the journey are simply added, thus avoiding the introduction of essentially arbitrary weightings, to provide a total travel time index. This index thus measures the levels of accessibility provided by the public transport system and it should be noted that as the index relates to the system rather than to the individual it has no behavioural foundation. The total travel time index is also utilized in the research into the accessibility of branch libraries by public transport reported in Chapter 11.

CHAPTER 3
DESCRIPTION OF SOUTH YORKSHIRE WITH PARTICULAR REFERENCE
TO THE SHEFFIELD STUDY AREA

1. Geographical and historical background

The Metropolitan County of South Yorkshire was created, along with the five other Metropolitan Counties in England, in April 1974 as a result of the Local Government Act of 1972. It comprises the Metropolitan Districts of Barnsley, Doncaster, Rotherham and Sheffield. The location of these Districts is illustrated in Figure 3.1. South Yorkshire has a population of approximately 1.3 million (1981 Census). Sheffield is the main urban focus of South Yorkshire with a population of 537,557 (present on Census night, v. 530,843 usually resident, 1981 Census). The pre-1974 local government areas of Sheffield CBC, Stocksbridge UDC and the Bradfield and Ecclesfield Parishes of Wortley RDC form the present-day City of Sheffield. A significant proportion of Sheffield Metropolitan District is of a rural and semi-rural nature; indeed to the west it extends into the Peak District National Park. However, it is the built-up areas of Sheffield which form the study area for this thesis and this area is indicated in Figure 3.2.

Figure 3.1

South Yorkshire : local government areas

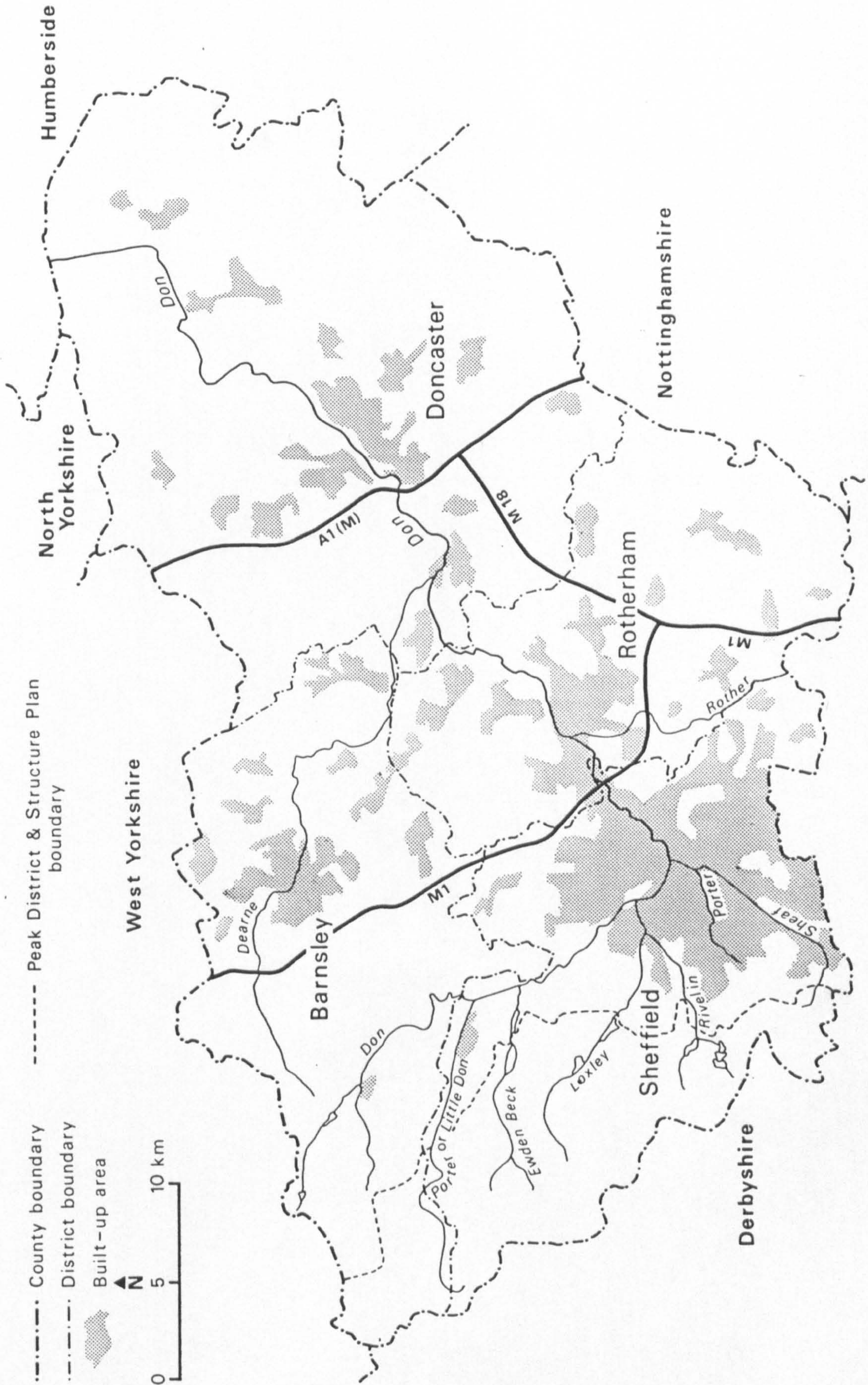
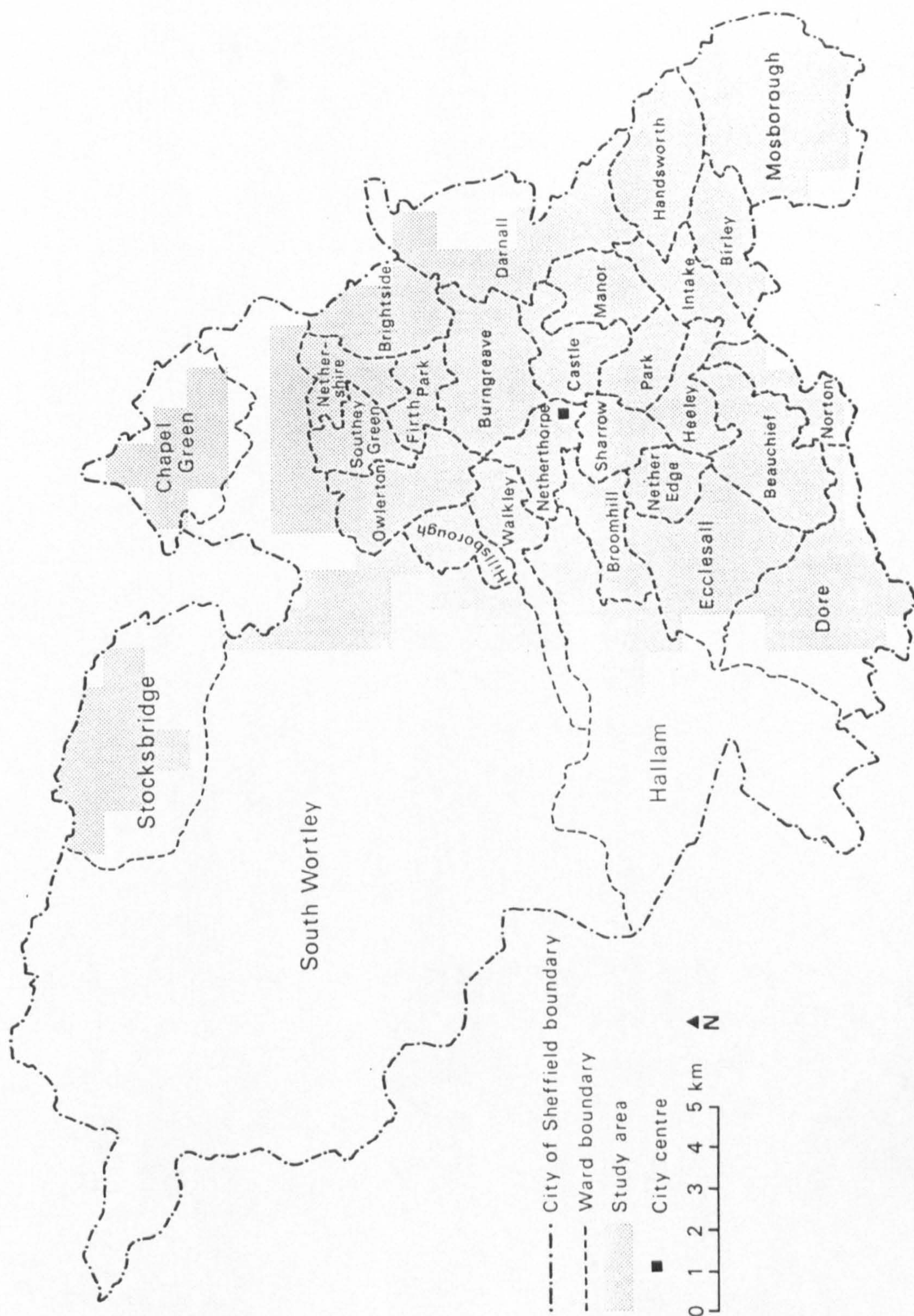


Figure 3.2

Sheffield : wards and study area

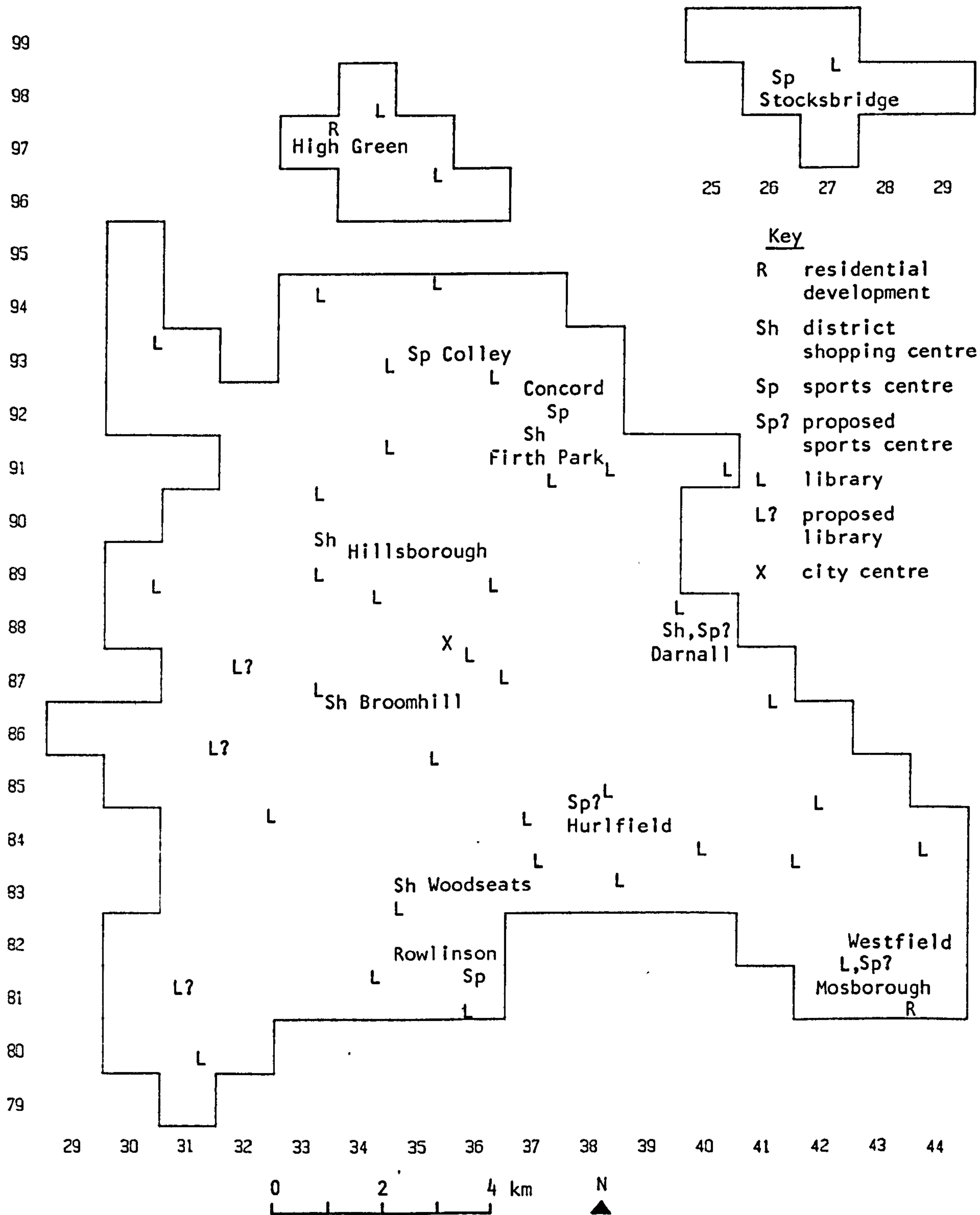


For much of the thesis the study area is composed of a sampling framework formed by the intersections of 1km National Grid lines. A sampling point was defined as lying at the intersection of these lines if the kilometre square of which the intersection formed the midpoint contained housing in Sheffield in so far as could be judged from the OS 1:50000 map and the A-Z 4" to 1 mile map. Figure 3.3 shows an outline map of the study area on which data and results are presented throughout the thesis. The axes refer to the National Grid 1km squares which form the basis of the sampling framework. The scale of the map is 1:100,000. The relation of this outline to the geographical areas of the city can be seen in Figure 3.2. It should be noted that the inset in the upper right portion of Figure 3.3 represents Stocksbridge which is actually situated north west of Sheffield city centre. The locations of the various facilities whose accessibility by public transport is investigated in later chapters are also shown in Figure 3.3.

Sheffield is sited around five convergent valleys at an abrupt right-angled turn of the River Don, from a south easterly direction to a north easterly direction. The streams and rivers of these valleys (the Don, the Loxley, the Porter, the Rivelin and the Sheaf) played an important role in the development of the early cutlery industry. When water power was replaced by steam power, local coal measures sustained industrial growth. In the

Figure 3.3

Map of the Sheffield study area showing
locations of facilities investigated



latter half of the 18th Century the population of Sheffield was around 30,000, whereas a hundred years earlier it was only 3,000 with another 2,000 in the villages and hamlets now part of modern Sheffield (How it was then : introducing Sheffield history, c.1978). Developments in the steel industry, such as the Bessemer convertor, led to large scale industrial expansion to the north east of the city centre, around the River Don, this expansion being aided by improved communications. Much of the present day heavy industry is still concentrated in this sector of the city and is highly segregated from residential areas. Such industrial expansion led to rapid population growth; one hundred years ago the population of Sheffield had increased to approximately 282,000. A more detailed account of the early history of the South Yorkshire area is provided by Hey (1979). A popular account of Sheffield and its history is to be found in Bunker's book Portrait of Sheffield (1972), whilst an authoritative, but now somewhat dated, work on the area is that prepared for the visit of the British Association for the Advancement of Science (Linton, 1956).

The physical relief of the area covered by the City of Sheffield is severe; the fact of Sheffield's growth around 5 river valleys has already been noted. This has hampered communications and building and indeed Hunt (1956) states that "it would be hard to find a better example of sustained correl-

ation between natural environment and the course of urban growth". Communications from Sheffield to the rest of the country are now good (the M1 motorway passes to the east of Sheffield and is linked to the city centre by dual carriageway, the fastest rail journey to London takes 140 minutes), but the hilly terrain has been a limiting factor in the siting of local roads and in particular of bus routes. Route 51, Lodge Moor - Herdings, covers some of the most difficult terrain in Sheffield, its lowest point being 205' (62.5m) above sea level at Queens Road, its highest point being 968' (295m) at Hallam Grange Road and its steepest gradient being 1 in 10 along East Bank Road (South Yorkshire Transport, 1983). In the field of housing many developments of the 1960s and 1970s were on undulating terrain which had been left vacant because it previously posed problems too difficult to solve. Such terrain still poses problems for the public transport operator trying to serve these housing areas.

A further feature of Sheffield which deserves mention is the large area covered by parks and open spaces, 3,275 hectares or 8.9% of the area of Sheffield Metropolitan District. This is a surprisingly high figure for a traditionally industrial conurbation and is reputed to be higher than that of any other industrial area in Britain (Municipal Yearbook 1981). Much former industrial land is becoming derelict as the economic

recession takes its toll on the steel industry and related trades. If new industrial enterprises cannot be attracted to these areas, such land could be converted to proper open space or could be used for future housing schemes. The location of housing and its characteristics are discussed in more detail in Section 3.

2. Population characteristics

Most of the data for this section is based on the 1981 Census. The series of Sheffield 1981 Census Reports produced by the Corporate Management Unit of Sheffield City Council provides useful interpretations of this wealth of data. Table 3.1 provides a summary of the statistics discussed here.

As mentioned in Section 1, the population of South Yorkshire in 1981 was approximately 1.3 million and the population of Sheffield on Census night was about 535,000. 51.6% of the usually resident population of Sheffield was female, 48.4% male and a total of 5,300 people were usually resident in communal establishments. The total number of private households was approximately 203,100, with an average household size of 2.59 persons. It should be noted that the usually resident population excludes the large number, approximately 12,000, of students living in Sheffield during term-time, but includes students normally resident in Sheffield who are studying away from home.

Table 3.1 Summary of statistics relating to population, employment, housing and car availability

	Sheffield %	South Yorkshire %	Metropolitan District Average %
<u>Population</u>			
0-4	5.1	5.8	6.1
5-15	15.7	16.8	16.8
16-59/64	59.3	60.2	60.0
≥ 60/65+	19.9	17.3	17.1
≥ 75	6.3	5.3	5.3
<u>Employment</u>			
Economic activity rates :			
Male	89.9	89.5	90.0
Female	63.6	59.5	62.3
Unemployment rates : overall	11.3	11.5	13.3
Male	14.0	13.4	15.7
Female	7.1	8.2	9.4
<u>Housing (by household)</u>			
Rented :	55.5	53.0	47.1
Council	45.0	42.8	36.2
Other	10.5	10.2	10.8
Owner Occupied	44.5	47.0	52.9
Sharing/lacking a bath	3.1	2.3	2.5
Lack of self-contained accommodation	0.7	0.5	0.7
Overcrowding	3.3	3.4	4.3
<u>Car availability (by household)</u>			
No car	51.8	49.6	48.2
2 or more cars	9.3	9.4	11.2

Source : 1981 Census

A comparison of Census data for Sheffield and the other Metropolitan Districts indicates that Sheffield experienced a very low number of births in the last ten years. In Sheffield 5.1% of the usually resident population is aged 0-4, compared with a Metropolitan District average of 6.1%. The corresponding figures for the 5-15 age category are 15.7% and 16.8%. At the other end of the age scale, 19.9% of Sheffield's usually resident population is of pensionable age (60/65+). This is the highest proportion for all Metropolitan Districts (average 17.1%). Although the proportion of residents aged over 75 is not quite so markedly above the national average, there will be considerable increases in this proportion during the 1980s. Thus the age distribution of the population of Sheffield is significantly different from that of other Metropolitan Districts, being heavily weighted towards older age groups. This distribution has important implications for social service provision, including the provision of transport.

The proportion of working age people (i.e. 16-59/64) in Sheffield is 59.3%. The economic activity rate for males is 89.9% in Sheffield, and there is little variation in this rate throughout the Metropolitan Districts, and that for females is 63.6%. This female activity rate is typical of the high rates found in the large cities; only the "mill" towns of West Yorkshire and Greater Manchester have higher rates. The lowest

female economic activity rates are found in the other Districts of South Yorkshire, although the County has experienced the greatest increase in female economic activity rates of any Metropolitan County since 1971. The Census figures for unemployment indicate that Sheffield had an overall unemployment rate of 11.3%, that for males being 14% and for females 7.1%. Compared to all Metropolitan districts, Sheffield had one of the lowest female unemployment rates. The male unemployment rate was higher than for the three other South Yorkshire Districts. Overall, Sheffield had the 24th highest unemployment rate of the 36 Metropolitan Districts at the time of the 1981 Census. By September 1983 the unemployment rate for Sheffield had risen to 14.6% according to Department of Employment figures (South Yorkshire Statistics 1983). (It should be noted, however, that the method for calculating unemployment used by the Department of Employment is different from that used in the Census. It is based on travel to work areas and relates the numbers of unemployed to the jobs provided in the area rather than to the employed population who are resident there. Because some jobs in Sheffield are taken by people from surrounding areas, this method will underestimate unemployment among Sheffield residents relative to the Census method.)

Having described the population characteristics of Sheffield in relation to other Metropolitan districts, it is worthwhile to look briefly at the spatial distribution of these characteristics. Figure 3.4 illustrates the distribution of the proportion of young people (0-15 years) in the Sheffield study area based on the 1981 Census. Each sampling point was allocated to the enumeration district in which it is situated and the number of 0-15 year olds as a percentage of the total population of that enumeration district was used as the input for the 1km square of which the sampling point is the midpoint. The percentages on which Figure 3.4 is based are shown in Appendix 3.1. Figure 3.5 and Appendix 3.2 provide the corresponding data for the distribution of the elderly (65 + years). For clarity, the following description relates to the ward level, there being 29 wards in Sheffield. The location of the wards relative to Sheffield city centre is illustrated in Figure 3.2.

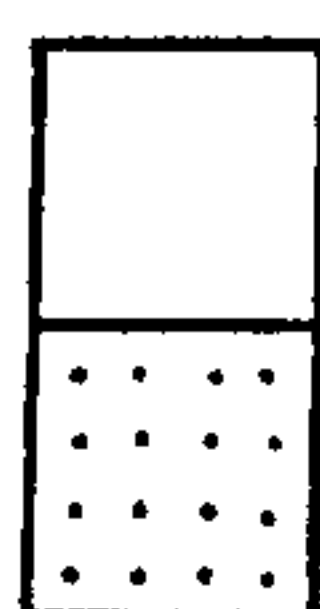
Wards with a high proportion of 0-4 year olds relative to the Sheffield average include Chapel Green, 9km to the north of Sheffield city centre, and Mosborough, 9km to the south east. In both these wards there has been considerable development of housing in recent years which has encouraged young families to settle there as part of the trend towards outward migration. The development of these two areas and the role played by public transport in this development is investigated in Chapter 8 of

Figure 3.4

Distribution of young people

Key

% of population aged 0 to 15



0 - 9

10 - 19



20 - 29

30 ≥

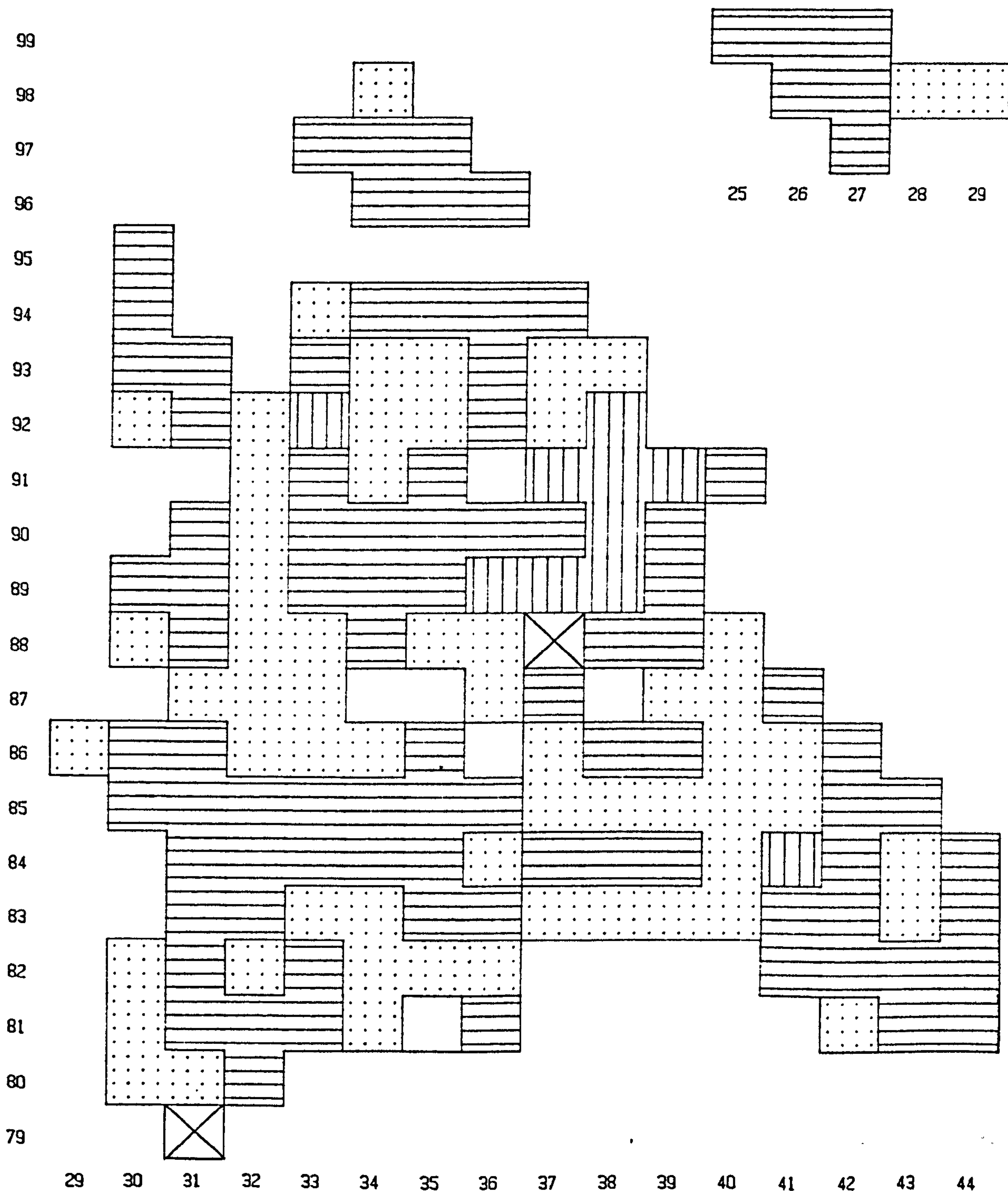
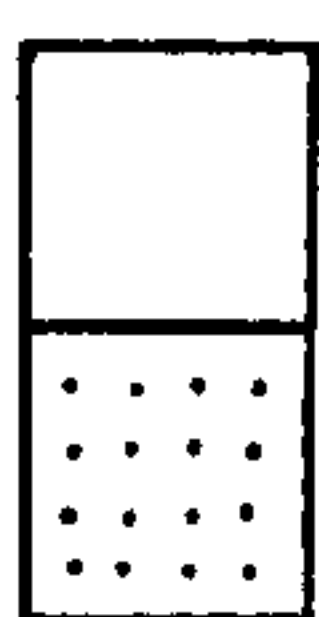


Figure 3.5

Distribution of the elderly

Key

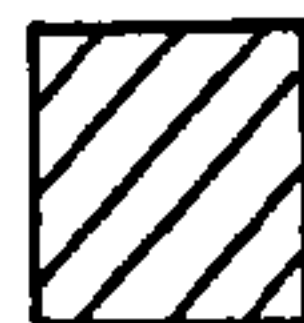
% of population aged 65 and over



0 - 9



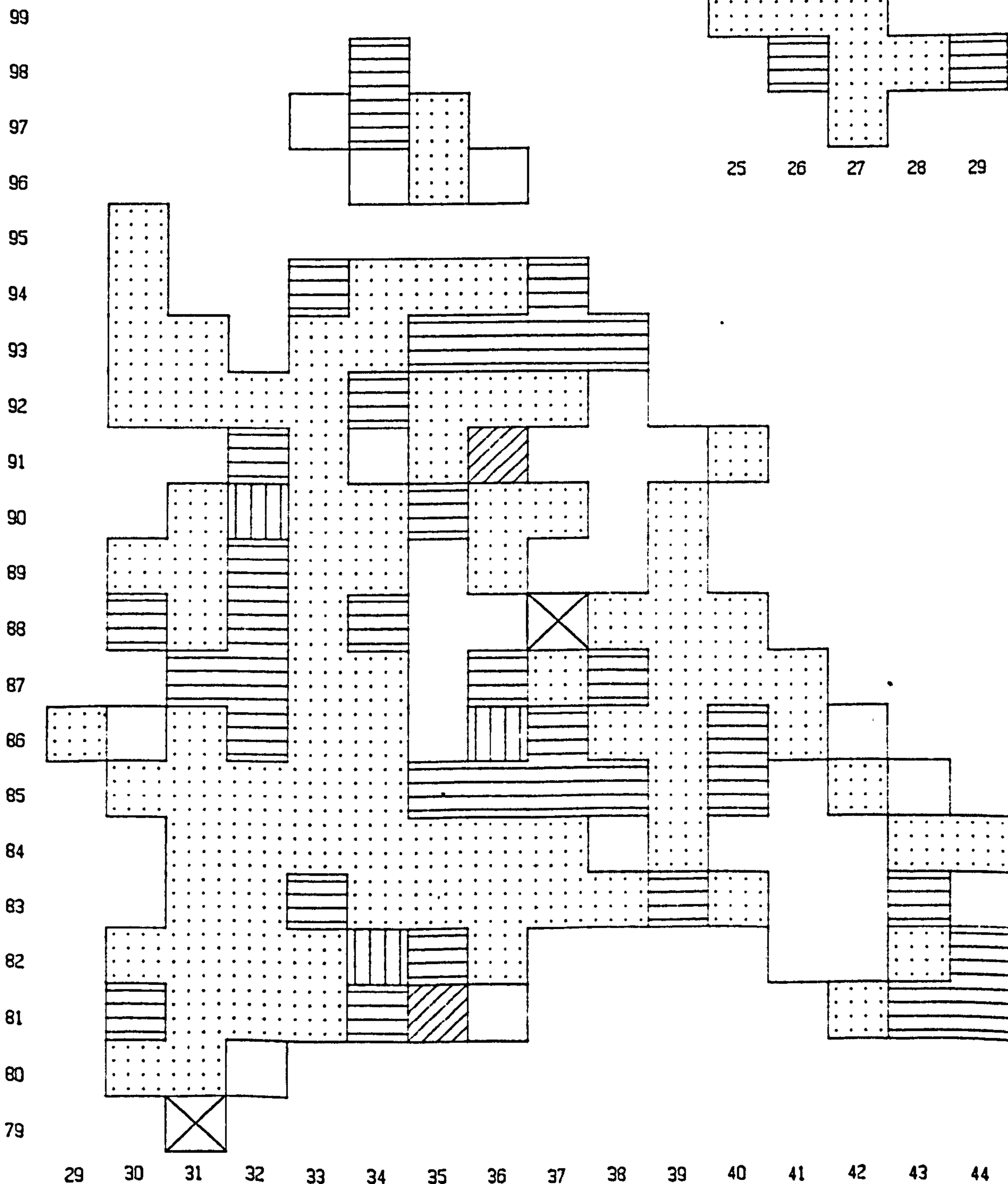
20 - 29



40 ≥

10 - 19

30 - 39



this thesis. Areas with a low proportion of persons aged 0-4, such as Nethershire 5km to the north of the city centre and Norton 6km to the south, have a more settled population with little recent housing development. The distribution of the population aged 5-15 is generally similar to the preschool distribution with a few notable exceptions. For example, Birley (6km SE of the city centre) has a high proportion of school age children but a very low proportion of children aged 0-4. Again this can be related to the timing of housing development; this ward includes areas which were developed during the 1960s and the families which settled there at that time have now stopped having children.

The distribution of the population aged 60/65+ is almost the opposite of the distribution of 0-4 year olds. In three wards, Nethershire, Norton and Park (3km to the east of the city centre) one quarter or more of the population is of pensionable age. However, the distribution of elderly persons is widespread with no one area of the city dominating, although the most recently developed areas have relatively small numbers of elderly people.

The highest levels of unemployment in Sheffield occur in wards in the centre of the city, with the exception of Southey Green, situated 5km to the north of the city centre, which has the fourth highest unemployment rate of the 29 wards at 17.2%.

Six wards had unemployment rates exceeding 16% and here male unemployment rates were even higher, exceeding 20%. A further six wards had unemployment rates between 12% and 15% and these are mostly wards immediately to the north of the city centre. Indeed the twelve wards with highest unemployment rates form one continuous area which very closely resembles the formally established Sheffield Inner Area. Thus there was a marked geographical pattern to unemployment in Sheffield in 1981 which has been intensified with increasing unemployment since that date.

3. Housing in Sheffield

From the 1981 Census 55.5% of the private households in Sheffield rent their dwellings (and of these more than 80% rent from the Council) compared with 53% in South Yorkshire and a Metropolitan District average of 47.1%. A breakdown of dwelling stock in Sheffield by age and tenure is given in Table 3.2.

Table 3.2 Age and tenure of Sheffield's dwelling stock

Tenure	Pre 1900	1900-1918	1919-1939	1940+	Total
Owner occupied	20,000	12,600	30,400	33,300	96,300
Local Authority	800	700	30,600	63,200	95,300
Other	10,200	4,400	2,200	3,200	20,000
Total	31,000	17,700	63,200	99,700	211,600

Source : City Trends 1981

The development of some of the major housing schemes in Sheffield is now described briefly in order to give some indication of the urban morphology of the city and its suburbs. Parson Cross in the Southey Green ward 5km north of the city centre consists mainly of inter-war semidetached council housing at low density producing a "seemingly vast uniform estate" (Sheffield Inner City Area : Area of worst deprivation profiles, 1979). The Manor estate 3km SE of the city centre consists of low density, low rise, pre and post 2nd World War local authority housing and Woodthorpe estate to the south of Manor is of similar design. In the 1950s Gleadless Valley Estate to the south east of the city centre was developed with tower blocks in spite of steep slopes, whilst on the southern edge of the city the Greenhill project, commenced in 1953, was mainly low rise.

Redevelopment from slum clearance commenced on a large scale at Park Hill, immediately to the east of the city centre, with high density multi-storey dwellings whose design was based on the concept of street decks giving one continuous building contoured along the hillside. After its construction this development attracted world-wide acclaim, but it is now realised that such housing is far from ideal, particularly for families. In 1967 the boundary of the City of Sheffield was extended to the south east to incorporate the Mosborough area in order to cater for the City's housing needs. An original target population of 81,000

was anticipated by 1986 to be housed in 18 planned townships comprising a mixture of public and private housing. According to Potter and Thomas (1982) "the Mosborough extension of Sheffield is an example of a planned alternative approach [to population containment] which rejects the satellite New Town solution". However, at present the emphasis on local authority housing construction, although much reduced from former levels, is concentrated on redevelopment; between 1982 and 1985 almost 80% of the local authority building starts will be on redevelopment sites within the Inner Area (City Trends 1981). Esher (1981) describes the post-war building development of Sheffield.

Having surveyed briefly some of the main housing developments in Sheffield, it is interesting to study the spatial distribution of present day housing characteristics using data from the 1981 Census. In three wards Southey Green, Manor (3km SE of the city centre) and Park, over 90% of dwellings are rented, and in a further three wards, Nethershire, Norton and Castle (1km E of the city centre) the proportion is over 80%. In contrast in Hallam (5km W of the city centre) and Ecclesall (5km SW) less than 20% of dwellings are rented.

Three criteria are used in the Census to denote poor quality housing, namely sharing or lacking a bath, overcrowding and lack of self-contained accommodation. The three wards in Sheffield

with a large proportion of households who lack or share a bath, namely Broomhill, 10.9% (3km W of the city centre), Sharrow, 9.9% (2km SW) and Nether Edge, 8.8% (3km SW) are all areas where there is a high incidence of households not in self-contained accommodation. These are areas which contain many large houses now converted into flats and bedsits, and the absence of most student households from the 1981 Census may mean that these characteristics have been understated. Overcrowding is defined in the Sheffield 1981 Census Report series as occurring in households which have more persons than rooms (excluding small kitchens and bathrooms). By this definition only 3.3% of Sheffield households suffer overcrowding. In Castle, Manor, Southey Green and Burngreave (4.5km N of the city centre) over 5.5% of households are overcrowded. These wards have other features in common such as high proportions of large families, little owner occupied housing and high unemployment.

Whilst overcrowding occurs in areas with high proportions of rented housing, the other criteria of poor quality housing, sharing or lacking a bath and lack of self-contained accommodation, indicate that such housing is found in wards which are of a very mixed composition in terms of both housing types and socio-economic status of residents. The mixed nature of such areas requires careful evaluation if public transport services are to be effectively and efficiently provided.

4. The location of major trip attractors

As in most large western cities the important trip attractors in Sheffield consist mainly of industrial and commercial establishments and shopping facilities. Information relating to employment categories, industrial, office and shop floor space and the location of major employment establishments is available from the South Yorkshire Structure Plan Report of Survey Volume 2 (1977b) and such information, updated where possible from the 1981 Census and South Yorkshire Statistics 1983, is discussed here in order to establish the nature and location of the major trip attractors in Sheffield.

In 1981 3% of employed people resident in Sheffield were employed in primary industry. The corresponding figure for South Yorkshire is 12%, this higher figure reflecting the importance of coal mining in the County. 41% of people in employment in Sheffield were employed in manufacturing (including construction) and 57% in the services sector. The corresponding figures for South Yorkshire are 37% and 52%. Of particular note is the reduction of jobs in manufacturing industries over the last twenty years or so. For example, between 1961 and 1971 the number of jobs in Sheffield in the manufacturing sector fell by over 20,000 and in just three years, between 1975 and 1978 the number of people employed in metal manufacture in Sheffield decreased by 3,400 (9%).

Sheffield dominates South Yorkshire as the major office centre of the County. In 1982 there were 532,000 sq.m. of office floor space in Sheffield compared with 791,000 sq.m. for South Yorkshire as a whole. (However, in comparison with other major national centres such as Newcastle and Manchester, Sheffield has a much lower status as an office centre and this is partly due to the continuing dominance of Leeds as a regional centre for the Yorkshire area.) Shops in Sheffield covered 864,000 sq.m. in 1982 compared to a total for South Yorkshire of 1,807,000 sq.m., again indicating the dominance of Sheffield in terms of the urban structure of the County.

The location of major employment establishments with mainly "blue collar" jobs in Sheffield is concentrated primarily along two axes, the River Don to the north east of the city centre, this being principally the site of the heavy steel industry, and to the north west also in the valley of the Don. There is also a cluster of such establishments to the south west of the city centre. The location of major employment establishments with mainly "white collar" jobs is much more concentrated in the city centre and to the south west of the centre. Two notable employers in this category are the Midland Bank Headquarters and the Manpower Services Commission. As has already been stated, the economic recession has had a particularly severe effect on employment in the manufacturing and construction industries.

This means that in terms of journey to work movements trips are becoming increasingly focused on the city centre. The importance of the city centre as a focus for trips is furthered by its role as a major shopping centre. Two other major trip attractors worth mentioning are the University and the Royal Hallamshire Hospital. These are located approximately 1.5km to the west of the city centre and they place major demands on public transport services. Indeed to cater for people visiting and working in the new hospital, the frequency of buses serving the hospital (Service 60) was increased from 5 per hour during the midday period on weekdays in October 1978 to 10 per hour in September 1979.

It is worth noting that Sheffield city centre itself is rather diffuse, with the Sheaf and Castle markets through to the Fargate precinct forming one major shopping centre and the pedestrianized Moor forming the other. This layout, combined with the non-central location of the major bus station (Pond Street), has created problems in the routing of buses so as to provide adequate access to all parts of the city centre. In spite of the layout of the city centre, Sheffield as a whole is a relatively compact and centralized city. Recent decreases in manufacturing employment have resulted in an overall concentration of trip attractors in the city centre and to the immediate west and south west of the centre. Such a concentration of trip attractors has important implications for the operation and viability of public transport services.

5. Car availability levels

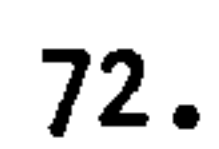
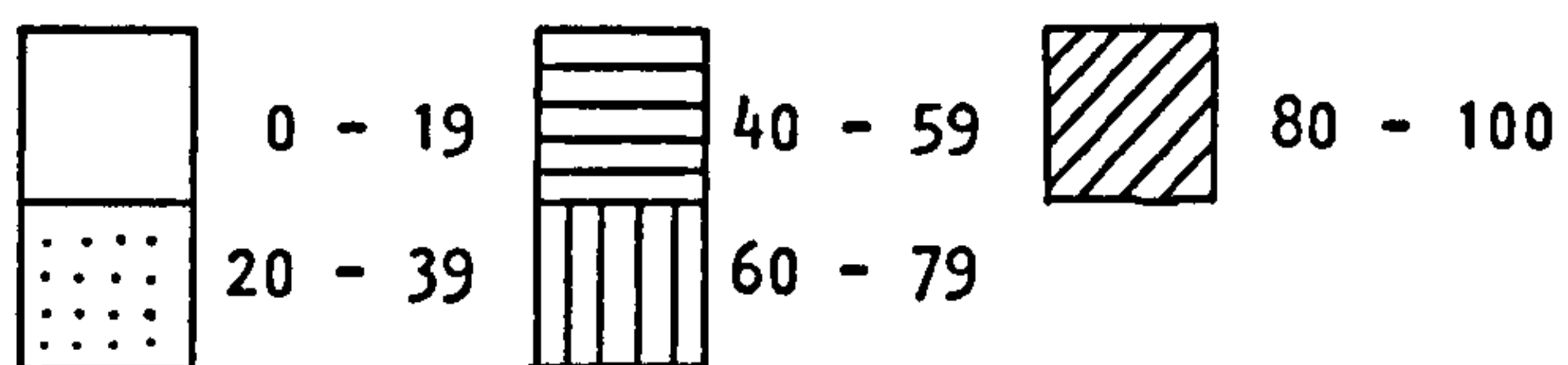
In 1981 49.6% of households in South Yorkshire had no car available for use by members of the household, whilst for Sheffield the proportion was slightly higher at 51.8%. In 1971 59.1% of households in Sheffield did not have a car. The 1981 Metropolitan District average for the proportion of households without a car was 48.2%, but the average figure conceals great variation, from 61.8% for Liverpool to 26.9% for Solihull. Sheffield had the 10th highest proportion of households without a car of the 36 Metropolitan Districts. 9.4% of households in South Yorkshire had two or more cars compared with 9.3% in Sheffield.

Figure 3.6 shows the distribution of the proportion of people in households without a car in the Sheffield study area based on the 1981 Census. The percentage of people in households without a car in the enumeration district in which a sampling point is situated is shown for the 1km square of which the sampling point is the midpoint. The percentages on which Figure 3.6 is based are shown in Appendix 3.3.

A study of the proportion of households without a car at the ward level in Sheffield indicates that households in wards in the centre of the city are least likely to own a car. The proportion of households without a car reached 73.3% in the Castle ward,

Distribution of people in households
without a car

% of people in households without a car



immediately to the east of the city centre. In five wards around the city centre the proportion of households without a car was over 68%, whilst a group of five wards to the north of the city centre and Norton to the south had rates of over 55%. At the other end of the scale, in the wards of Hallam, Dore and Ecclesall to the south west of the city centre, less than one third of households lacked a car whilst in each of these three wards over 20% of households had 2 or more cars, compared with 9.3% for Sheffield as a whole.

A marked geographical pattern thus emerges when the proportion of households without a car is studied at the ward level in Sheffield. This pattern is similar to that displayed by other Census data; areas with a high proportion of households without a car tend to be associated with renting, especially from private landlords, overcrowding, large households and unemployment. It should be remembered that whilst dependence on public transport is a mirror image of car availability, even in car-owning households some members of the household may be dependent on public transport at certain times of the day.

Another statistic relating to car availability in the 1981 Census concerns mode of travel to work, analysed at the 10% level only. 43.2% of people living in Sheffield and travelling to work travel by car, 41.9% by bus or train, 1.9% cycle and 12.9% walk. However, if the data relating to people both living and working in Sheffield is considered, then approximately 6,000 more people travel by public transport than by car.

6. Public transport in South Yorkshire

Public transport services in South Yorkshire have been operated by South Yorkshire Passenger Transport Executive since 1974 on behalf of South Yorkshire County Council which is the Passenger Transport Authority. The Executive then took over the municipal transport undertakings of Sheffield, Doncaster and Rotherham and has since bought up some other local operators, for example Booth and Fisher Motor Services based at Halfway, to the south east of Sheffield, in 1976. In Barnsley, services are operated by Yorkshire Traction, an NBC subsidiary, but still within the policies laid down by the County Council. In total the National Bus Company operates about 29% of bus mileage in South Yorkshire. Much of the statistical information presented below was obtained from South Yorkshire Transport's booklet Facts and Figures, Spring 1983.

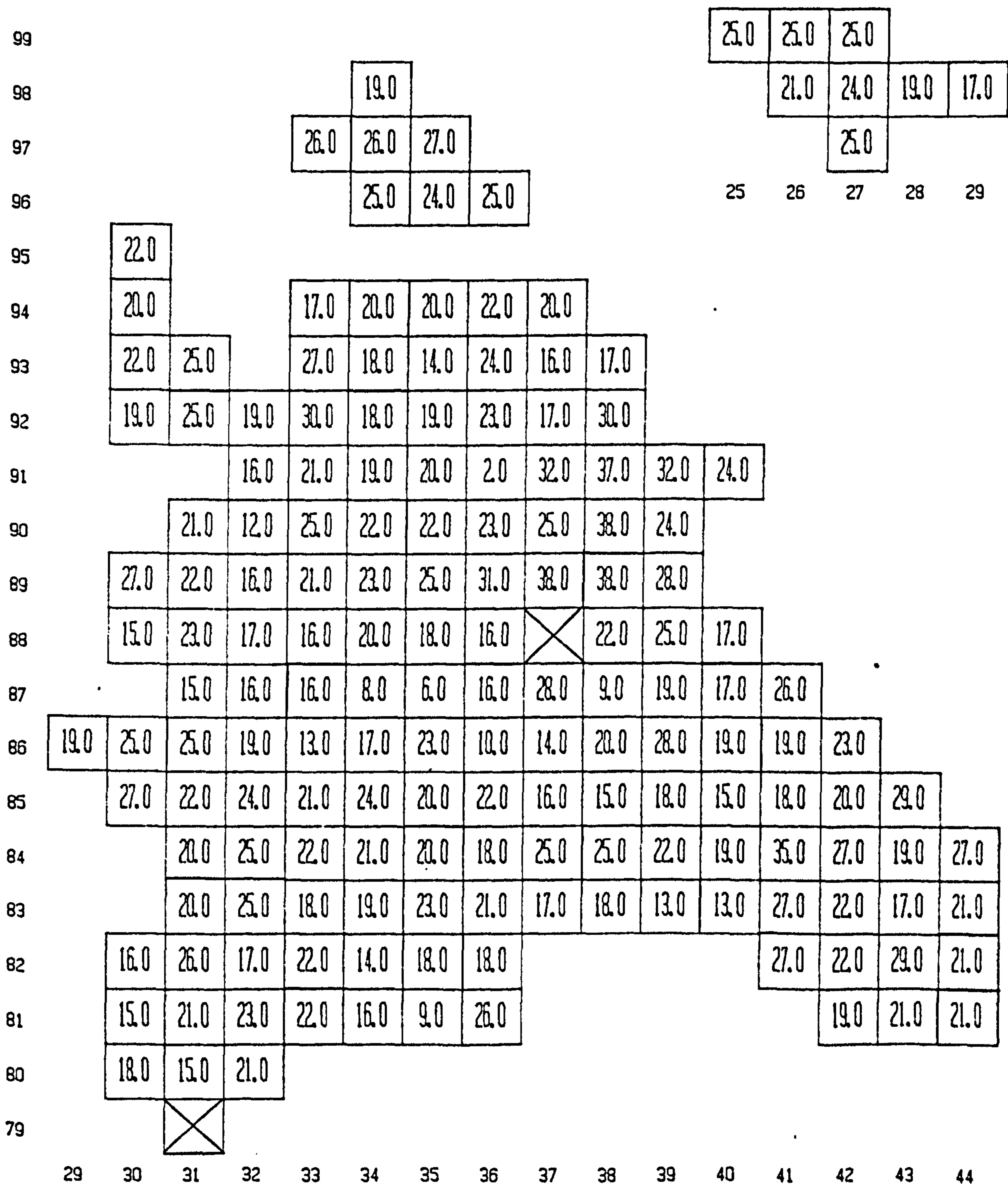
In January 1983 South Yorkshire Transport had a fleet of 1,115 buses, 727 being based in the Sheffield operating district. 36.2 million vehicle miles were run by all South Yorkshire Transport's buses between April 1981 and March 1982, of which 24.1 million miles were in the Sheffield district. During this period 261 million passengers were carried by South Yorkshire Transport, with the number of passengers using buses in Sheffield on an average working day being 476,000. Rail services play only a limited role in local travel, with South Yorkshire County

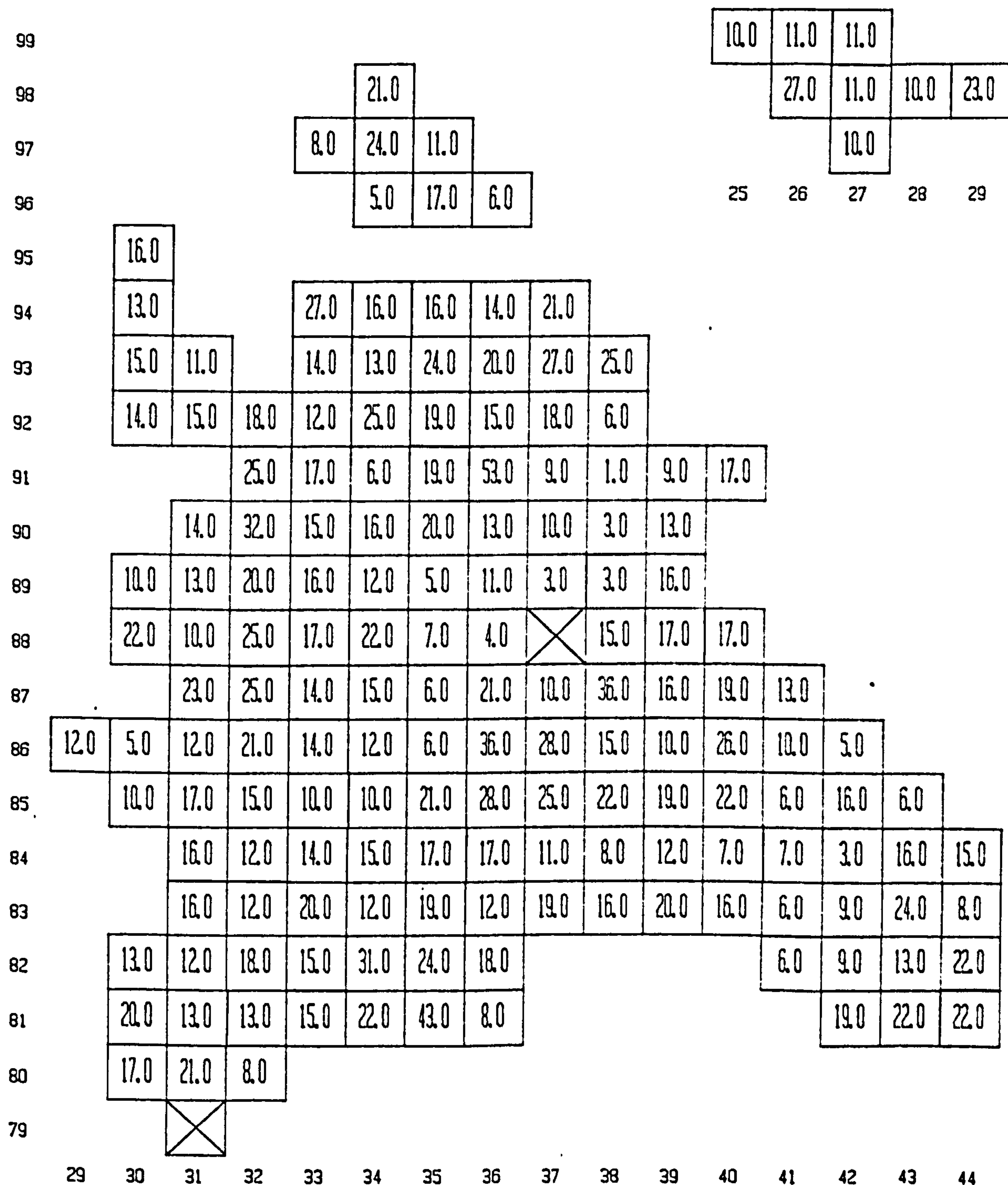
Council supporting services on only three lines (Sheffield-Barnsley-Wakefield-Leeds, as far as Darton, Sheffield-Rotherham-Doncaster-Hull/Cleethorpes, as far as Thorne North and Thorne South and Sheffield-Worksop-Retford-Lincoln, as far as Kiveton Park). Because of the relative unimportance of local rail services in South Yorkshire, the focus of this thesis is on public transport in the form of bus services.

7. Conclusion

The City of Sheffield covers an area of 37,000 hectares, of which a significant part particularly in the west is of a rural nature, indeed some is even uninhabited moorland. However, the built-up area itself constitutes a fairly compact city and, largely because of physical and historical factors, land use and population characteristics exhibit a sectoral rather than a radial pattern. Most of the major trip attractors are located in the city centre and to the immediate west and south west of the centre. The large population has only modest levels of car ownership. These features combine to produce an environment conducive to the operation of a public transport system. In order to investigate whether Sheffield's public transport system is successful (especially in the provision of accessibility) it is firstly necessary to ascertain the aims and objectives for public transport. This is done by an examination of the policy documents of South Yorkshire County Council and Passenger Transport Executive in Chapter 4.

In many respects Sheffield is similar to other large northern and midland cities. Thus the findings of this study of the relationship between public transport provision and accessibility in Sheffield have relevance in a wider context.





Percentage of people in households
without a car

79.

CHAPTER 4

THE PLANS OF SOUTH YORKSHIRE COUNTY COUNCIL : AN ASSESSMENT WITH RESPECT TO PUBLIC TRANSPORT ACCESSIBILITY

1. Introduction

The focus of this study is on the level of accessibility provided by public transport in Sheffield. In order to place the study in context it is necessary to investigate the policies contained in the planning and transportation documents of South Yorkshire County Council, the County Council being the tier of local government responsible for strategic planning and transport provision for Sheffield and the other three Metropolitan Districts of South Yorkshire. Furthermore, from some of the policies relating to accessibility hypotheses can be formulated and then tested to assess whether these policies have been successfully implemented.

In this chapter the plans of South Yorkshire County Council are assessed with respect to accessibility by public transport and hypotheses are derived. The development of accessibility measures to test these hypotheses forms the subject of later chapters.

2. The plans of South Yorkshire County Council

The main planning document to be assessed here is the Structure Plan for South Yorkshire which was submitted to the Secretary of State for the Environment for approval in February 1978, approved with modifications in December 1979 and became operative in January 1980. The Structure Plan was prepared under the 1971 Town and Country Planning Act and covers a ten year period up to 1986. Besides the Written Statement (South Yorkshire Structure Plan, 1978, 1981) which forms the Structure Plan itself, a wealth of other material has been published and much of this is of interest here.

The Written Statement is supplemented by a four volume Report of Survey (South Yorkshire Structure Plan, 1977-1978) dealing with the definition of key issues, the development of policies from these issues and the changes which occurred between the publication of the Draft Written Statement and the revised Written Statement. As required by the 1971 Act, public participation has been an important feature of the structure planning process and a Participation Statement has been published by the County Council (South Yorkshire Structure Plan, 1978). Many Technical Reports have been published to augment the details contained in the body of the Structure Plan and a series of Structure Plan Discussion Papers also exists, covering such topics as reports on Councillor Open Days, minority viewpoints

and the public's view on the provisional transport plan. (Only the technical reports and discussion papers particularly relevant to this thesis have been included in the bibliography.) Two institutions were involved in some of the public participation work and their reports, South Yorkshire Structure Plan Public Attitude Survey (Courtenay and Field, 1975) and Community Panels in South Yorkshire (Hedges and Stowell, 1977) are also relevant. Darke (1979) has reviewed the role of public participation in the South Yorkshire structure planning process.

A public examination was held to investigate the Structure Plan as submitted for approval in September 1978 and it is necessary to bear in mind the amendments recommended in Examination in Public : Report of the Panel (South Yorkshire Structure Plan, 1978) when assessing the Structure Plan. Some of these amendments were incorporated into the Secretary of State's schedule of modifications. A new edition of the Written Statement was published in 1981 which includes the Secretary of State's modifications and letter of approval. This forms the basic strategic planning document for the County.

In spite of the opportunities provided for the public to participate in the structure planning process, much comment and criticism of the Structure Plan appeared in the local newspapers throughout the plan's various stages. The relevant items published in the two Sheffield papers, the Morning Telegraph and the Star, have been considered in this assessment of South Yorkshire's plans.

Attention has also been focused on various documents relating to transport planning in South Yorkshire. These include the Sheffield and Rotherham Land Use Transportation Study (Sheffield and Rotherham : a transportation plan for the 1980s, 1976), the findings of which were incorporated into the Structure Plan, a policy statement by South Yorkshire County Council and South Yorkshire Passenger Transport Executive entitled Passenger Transport in South Yorkshire (1975) and the Passenger Transport Executive's Transport Development Plan (1978) which was based on the above policy statement. Also important are the County Council's annual Transport Policies and Programmes.

3. The principles and scope of the Structure Plan

The basic philosophy on which the Structure Plan is based is stated in the Written Statement : "The Structure Plan has evolved from certain guiding principles, the most important of which is to favour the "have-nots", i.e. those sections of the population and areas of the County in greatest need of help" (South Yorkshire Structure Plan, 1978). This policy of favouring the "have-nots" is certainly important in the context of providing accessibility for those people dependent on public transport. The plight of the carless is recognised more explicitly in that part of the Written Statement which discusses social aims : "Socially, the strategy aims to assist the sections of the

population in greatest need. One such group is made up of those (including the poor, the old and the young) who have to travel by public transport because they do not have the regular use of a car. They find it more difficult than car users to get to work, shops and recreation facilities". The relationship between transport and land use is clearly acknowledged : "transport results from the relationships of everyday activities and is not an end in itself. Hence the concept of an integrated planning process for land use and transport is central to the structure planning process" (South Yorkshire Structure Plan Report of Survey, 1977b). This means that policies which have a bearing upon accessibility by public transport will be contained not only in the topic of transport but also in those topics dealing with the location of facilities.

The County Council decided that the Structure Plan should contain both prescriptive and advocative policies which would be suggested for implementation by other agencies. This policy has ensured that the Structure Plan covers a wide spectrum of issues, although the four Metropolitan District Councils of South Yorkshire in particular have been critical of the County Council for encroaching on planning matters which they feel should be dealt with at a local level.

The Structure Plan deals with seven major topics, namely employment, population and housing, environment, recreation, shopping, surface minerals and transport, and indicates the County Council's policies and proposals under each heading. Obviously some of these headings are more important than others for the present purpose. Some of the policies for employment are concerned with the journey to work and much of the impetus for improving public transport services comes from a recognition of the need to enable workers to reach employment, especially within the County Council's framework of job priority areas. (It should be noted however that the Panel of the Examination in Public recommended the deletion of job priority areas and the Secretary of State approved the Structure Plan subject to the replacement of the concept of job priority areas with the concentration of industrial investment in areas of highest potential.) In considering the location of recreational and shopping facilities, attention is frequently paid to their accessibility for those without a car and so these policies deserve attention here. The section dealing with transport covers four major issues; public transport, road improvement schemes, car parking policies and freight. Although several of the road improvement schemes incorporate bus priority measures, the latter three aspects are not relevant to this study.

Three major alternative strategies were defined and tested to see how well they performed against various objectives in order to determine the final strategy. The objectives were ranked in order of importance and two of them clearly indicate the priority attached to accessibility in the early stages of the formulation of the Structure Plan. The objective ranked 8th was that there should be new housing in areas with good environmental standards accessible to social and community facilities and the 17th objective was that shopping facilities should combine the advantages of easy accessibility for the shopper with an adequate range of goods in each centre.

The following three sections examine the attention paid in the Structure Plan to the provision of accessibility in the policies concerning transport, shopping and recreation.

4. Policies relating to public transport

The background information for the transport policies contained in the Structure Plan comprises three main elements; the three Land Use/Transportation Studies covering the County, a computer based description of transport characteristics referred to as SYCTAS (South Yorkshire County Transport Analysis System) and the Public Attitude Survey supplemented by the results of other public participation schemes.

The key issue concerning transport was defined as "What level, pattern and type of transport provision will best serve the future distribution of population and employment in South Yorkshire?" (South Yorkshire Structure Plan Report of Survey, 1977b). Five sub-issues were identified, the two most important in this context being "How can transport provision and the nature and location of development be related to give good accessibility to a choice of homes, work-places, recreation, shopping and other facilities?" and "What level and form of public transport provision is required to provide adequate mobility for those without personal transport?"

Evidence from the Public Attitude Survey on the attitude of South Yorkshire residents suggests that "the majority of people without cars do not regard themselves as socially deprived, although they may have particular complaints about public transport services" (South Yorkshire Structure Plan Report of Survey, 1977b). Problems concerning public transport identified by the two Structure Plan kits related to the inadequacy of late evening bus services which limits opportunities to enjoy entertainment in the town centres. Whilst the frequency and coverage of public transport services within the County were generally satisfactory, particular problems included the difficulty of making public transport journeys in orbital directions within urban areas, the relative deficiency in the level of service in some rural areas,

for example to the north east of Doncaster, and the location of rail lines away from main trip generators and attractors which limits the scope for making greater use of rail for local passenger transport. It is interesting to note that in 1974 (the time of the Public Attitude Survey) substantially less satisfaction with fare levels was experienced in those areas where fares per trip were higher than the average for the County.

The policies proposed in the Structure Plan for transport were influenced strongly by "the desire for an effective, efficient and cheap public transport service, together with the general Structure Plan strategy of helping those in greatest need" (South Yorkshire Structure Plan Written Statement, 1978). Giving priority to public transport was consistent with the public participation response; 96% of respondents thought bus and train services should be improved, with greater frequency, punctuality and reliability of services being the improvements most frequently sought.

The relationship between land use and transportation was made explicit in Policy T2, which was designed to minimise the costs of service provision and provide a better service to passengers : "The location and layout of industrial, commercial, residential, education, shopping and recreation developments will provide for economical public transport operation". It was how-

ever recognised that "action to minimise travel by land-use planning is limited by current planning permissions in the short term" (South Yorkshire Structure Plan Report of Survey, 1978). The Panel of the Examination in Public decided that this policy was too restrictive, seeking to make development subject to public transport rather than public transport serve development. The Panel suggested that public transport services should be more flexible and advocated the replacement of Policy T2 with the following : "Public transport should, where possible, be provided to assist the development of industrial, commercial, residential, educational, shopping and recreational facilities". This amendment was approved with slight modification by the Secretary of State for the Environment.

One of the most important revisions made to the Draft Written Statement was the deletion of Policy T1 part of which stated that in the period up to 1986 bus fares would not be increased. This cheap fares policy generated much hostility from certain consultees largely as a result of the anticipated increased rate demand, and was widely criticised in the local press. Of the general public who commented on the transport policies in the draft Structure Plan "many were very strongly opposed because of the apparent cost involved" (South Yorkshire Structure Plan Participation Statement, 1978). However, although still believing that "containment of fares will bring social and

economic benefits and the subsidy will not form an excessively large proportion of public expenditure in South Yorkshire", the County Council took the view that its "fares containment policy is not appropriate policy for inclusion in the Structure Plan" (South Yorkshire Structure Plan Report of Survey, 1978). Indeed a policy of fares containment has been pursued by South Yorkshire County Council. Fare levels were rationalised in 1975 to provide a county-wide fare scale and have not been increased since, although in March 1984 a restructuring took place such that all fares are now in multiples of 5p. For 5p it is possible to travel up to 1.5 miles (2.4km) and a 12 mile (19.3km) journey costs 20p or 25p, compared with 80p at peak times in West Yorkshire and 90p in the West Midlands. (Morning Telegraph, (Sheffield) 4th February 1984). The general rate of inflation has been such that the purchasing power of £1 in 1983 compared with 1975 was 40p (Department of Employment, 1984) and thus the containment of fares represents a decrease of 60% in real terms. To maintain the level of bus fares and services determined by South Yorkshire County Council necessitated a grant of £43.3 million in 1982-83 plus a further £25.1 million for concessionary fares for the elderly, children and the disabled (South Yorkshire Statistics, 1983).

Public transport service improvements singled out for attention include circular and cross-town services in Sheffield and Rotherham in order to "facilitate social and recreational journeys generally (and access to some district shopping centres)" (South Yorkshire Structure Plan Written Statement, 1978). Also mentioned is the poor accessibility to sports centres identified in many parts of the County which can only be resolved by improving public transport services where existing centres are concerned. Following the publication of the Sheffield and Rotherham Land Use Transportation Study in April 1975 a public review was conducted, consisting of kits for organisations, questionnaires, exhibitions, five public meetings and extended interviews with 37 households. One of the findings of the public review was that the proposed new circular bus services produced a very favourable response, with 21 of the families in the extended interview believing that these services would satisfy a number of their travelling needs, "in some cases enabling them to make trips to friends and places like the doctors and dentist which at present they can only make with the greatest difficulty" (South Yorkshire Structure Plan Discussion Paper, no date b).

The Structure Plan policies lay great emphasis on the role of public transport and support the notion that South Yorkshire County Council is aware of and wishes to mitigate the problems

experienced by those reliant on public transport in gaining access to desired facilities. This emphasis recurs throughout the planning and transportation documents produced by the County Council and the Passenger Transport Executive and is of central importance to the theme of this study.

5. Policies relating to shopping

In the second volume of the Report of Survey (South Yorkshire Structure Plan, 1977b) four main types of shopping centre were identified, namely (i) the four main centres of Sheffield, Barnsley, Doncaster and Rotherham, (ii) district and small town centres, (iii) out-of-centre superstores, and (iv) local shops. Information regarding shopping was obtained from a sample of the public who kept diaries for all visits to shops in one week. The Report states that "Shopping has been shown to be closely related to transport, and changes in the use of different types of transport will affect the balance of spending between the major centres and other shops. It is important that the strategic policies for shopping and transport should be related to each other".

The key issue was stated as : "What levels and distribution of retailing are required to meet the future needs of the population of the County and those neighbouring areas which are presently served by centres in the County?"

Research for the Structure Plan indicated that only about a quarter of the retail spending of shoppers who use public transport is done outside the four main centres. It is thought that this low proportion can partly be explained by the present pattern of bus routes, which tends to focus on the main town centres rather than on the larger district and smaller town centres. A further factor to emerge from a survey of shopping visits was that shoppers travelling by bus or on foot accounted for only 16% of the sales of the three superstores in the County. These figures indicate that those reliant on public transport are relatively disadvantaged in terms of accessibility to district and small town centres and out-of-centre shopping facilities.

In accordance with the basic philosophy of the Structure Plan of helping the "have-nots" (in this case those without access to a car), Policy S3 was stated in the Written Statement as "Shopping development outside existing centres will not be permitted" in four types of situations, the fourth one being "it would not be conveniently located for those reliant on public transport" (South Yorkshire Structure Plan, 1978). It is of considerable interest that this fourth clause regarding accessibility by public transport to out-of-centre shops did not appear in the Draft Written Statement. It was added as a result of the concern expressed by the members of the public attending community panels (whose objective was to allow members to reach

considered and mature viewpoints) about "the disappearance of local shops and small shops and the problems of those who are least mobile (non-car owners, the aged, etc) who would benefit least from out-of-town centre superstore development" (South Yorkshire Structure Plan Report of Survey, 1978). The Panel of the Examination in Public, however, recommended that Policy S3 be deleted and rephrased in a positive form, with no mention being made of the role of public transport. In the final approved plan there is a clause relating to public transport, namely that shopping development outside existing centres will not be permitted where "it could not be readily served by public transport", the emphasis here being on a more flexible approach to public transport provision than envisaged in the submitted Written Statement.

Another policy to be changed as a result of the consultation programme after the publication of the Draft Written Statement was the policy dealing with improvements to district and small town centres. In the Draft Structure Plan individual centres were listed, but the District Councils strongly objected to this. The final Policy S2 is as follows : "Local plans will make provision wherever possible for improvements to the accessibility and environment of district and small town centres". One of the four measures included in this policy is "improvements to local bus services where appropriate". However, in a discussion of the

implications of the Structure Plan for each District of South Yorkshire, the Written Statement states with respect to Doncaster that "shopping developments will be encouraged in smaller centres such as Thorne, Bawtry, Bentley, Tickhill, Woodlands and Mexborough", with respect to Rotherham that improvements to bus services and small scale environmental improvements "may be particularly appropriate at Maltby, Swinton and Wath" and with respect to Sheffield that "shopping activity will be encouraged in district centres such as Stocksbridge, Chapeltown, Broomhill, Darnall, Firth Park, Hillsborough and Woodseats by making improvements to local bus services" (South Yorkshire Structure Plan, 1978). The Secretary of State for the Environment has deleted this section of the Written Statement in approving the Structure Plan as the contents are said to be generally too detailed for inclusion.

The Structure Plan policies on shopping show clearly that the County Council is aware of the problems experienced by those without the use of a car in gaining access to district and small town centres and to out-of-centre superstores. The methods by which these problems can be alleviated are seen in terms of both the improvement of public transport and the careful location of new shopping facilities.

6. Policies relating to recreation

In the second volume of the Report of Survey (South Yorkshire Structure Plan, 1977b) the key issue for recreation was stated as "What provision and pattern of leisure facilities will best meet the recreational needs of the population of South Yorkshire in the future?" Four sub-issues concerning urban open space, informal countryside recreation, indoor sports centres and golf were identified. A review of existing provision for recreation in South Yorkshire led to the conclusion with respect to informal countryside recreation that "another problem is the need to cater for people who are without the use of a car for access to the countryside". A further problem relating to the carless was that "Young teenagers have particular needs for entertainment which are not being fully met at present... The Dearne Valley and the rural areas of South Yorkshire are relatively poorly served by public transport from the four main town centres in the late evening".

A technical report has been published (South Yorkshire Structure Plan, 1977) which investigates the question of accessibility to recreation with the aim of establishing which areas of the County are poorly served by countryside recreation areas or indoor sport centre facilities. Three approaches were investigated, namely (i) areas served (by direct bus route), (ii) deterrence function, and (iii) catchment area. It is stated that

"without exception, access by car from any given zone is superior to access by public transport. For this reason emphasis was given to solutions for the public transport deficiency areas. Poor accessibility has been considered to be more severe where it coincides with high dependency on public transport". The major deprived areas with respect to countryside recreation areas were identified as (i) parts of south eastern Sheffield, (ii) Rotherham and (iii) the towns to the north of Barnsley.

In the Written Statement (South Yorkshire Structure Plan, 1978) the third policy for recreation deals with the location of new recreational facilities : "New recreation facilities will only be provided on sites which have, or at reasonable cost can have, good public transport services, unless these facilities are (a) sited within convenient walking distance of the majority of their potential users, or (b) connected with leisure activities which are so specialised in their site requirements that considerations of accessibility by public transport must take low priority". It is worth noting that in the Draft Written Statement (South Yorkshire Structure Plan, 1977) the policy was proposed without either of the two provisos. These were added as a result of the consultation process, many of the consultees believing that the policy was too restrictive as it stood. According to the Participation Statement (South Yorkshire Structure Plan, 1978), however, there was overwhelming support

from the general public for all aspects of recreational policies as stated in the Draft Written Statement. The Panel of the Examination in Public (South Yorkshire Structure Plan, 1978) recommended the deletion of this policy on the grounds that it was expressed in a negative way. The Panel was of the opinion that if public transport services to proposed sites are inadequate, consideration should be given to their improvement rather than to banning the provision of recreation facilities. The substituted policy is as follows : "Special consideration will be given to the provision of new recreational facilities on sites which have, or at reasonable cost can have, good public transport services; or sites which are within convenient walking distance of the majority of their potential users". This amendment was incorporated into the Structure Plan as approved by the Secretary of State for the Environment.

It can be seen that the problems of gaining access to recreational facilities experienced by people without the use of a car have played an important part in the formulation of South Yorkshire County Council's policies for recreation. It remains to be seen how far such policies, especially in their approved form, will help to overcome these problems, a theme which is investigated in Chapter 10 with respect to indoor sports centres.

7. The needs of minority groups

Attention has already been given to the key role played by public participation throughout the formulation of the Structure Plan for South Yorkshire. Within this the Social Aspects Group which was set up as part of the working arrangements for Phase II of the Structure Plan programme was very much aware of the need to give special attention to the requirements of minority groups within the community and suggested that four such groups should be recognised, namely (i) the old, (ii) the immobile (through physical handicap, low income or without access to a car, (iii) the young and (iv) those with low incomes:

Various research methods were used to assess the views of the young and the elderly on all topics considered in the Structure Plan. The need to focus on these groups when formulating transport policies is clearly seen in Phase 1 report on transport (South Yorkshire Structure Plan Discussion Paper, no date a) : "The elderly are particularly dependent on public transport and it is they who suffer most from reduced and infrequent services. The majority of children and adolescents rely on public transport for educational, social and work purposes". Another group identified for special consideration in this paper is those wives without direct access to a car, and "thus again the majority are dependent on public transport for work, social and shopping purposes".

The Discussion Paper entitled Minority viewpoints : a special report on the views of the young and old (South Yorkshire Structure Plan, 1975) brings together information concerning these two important groups of people who are largely without direct access to a car. The data on the views of the young were collected from three sources; the replies of the youngest age group (16-24 years) of householders interviewed in the Public Attitude Survey, a questionnaire for completion by young people who lived in a house where the householder was interviewed in the Public Attitude Survey and questionnaires and kits designed for completion by schools. Although limitations were imposed by the quantity and nature of the data, "some very useful pointers on the attributes, needs and satisfactions of young people in South Yorkshire have been identified in the analysis". Three sources were also used to obtain the views of the elderly. These were a conference entitled "Pensioners and Planners" arranged by the County Council and Age Concern with an attendance of 140 OAPs, the replies from the 65+ age group of the Public Attitude Survey and replies to the first Structure Plan kit by five Old People's Groups.

As regards young people, the greatest dissatisfactions were expressed concerning leisure, a critical area being in the rural parts of the County where "lack of provision coincides with the difficulty and cost of transport to facilities in the urban

areas". It should be noted that these views date from before the introduction in January 1975 of the standard fare for children of 2p up to the equivalent adult fare of 15p, and indeed the need for such a concessionary fare scheme was advocated by many young people, especially by school children in rural areas who have to use public transport for trips to leisure and shopping facilities in urban areas.

Young householders interviewed in the Public Attitude Survey comprised the age group to show least agreement with the statement "small local shops are best" and most agreement with "large shopping centres are a real help to the busy housewife". Such findings have important implications for future levels of provision of shopping facilities and public transport.

The conference to ascertain the views of pensioners identified three main problems faced by the elderly despite a general satisfaction with their lives. These problems were that too little is done to help old people stay within the community, the lack of suitable housing for the elderly and the inadequacy of bus services. Mobility was felt to be the key to these issues. Specialised housing was recommended to be located within close proximity to a bus service for "this form of transport is of vital importance to the elderly as a lifeline between themselves and the facilities they use" (South Yorkshire Structure Plan

Discussion Paper, 1975). Criticisms of the bus service related to the irregularity of buses and the inconvenience of bus routes but satisfaction was expressed about the concessionary fare scheme (free travel between 0930 and 1530 and between 1800 and 2230) and many OAPs felt that the planned extension of the scheme to allow travel between Districts would "open up further recreation and entertainment opportunities to the elderly". The analogy of the bus service as a lifeline is referred to again in the Discussion Paper ("for many of the elderly the bus service is a lifeline between their homes, their relatives, the shops and doctors surgery"), and the reliance of the elderly on this lifeline is "growing daily as local shops close down in favour of town centre supermarkets and the centralisation of doctors surgeries into health centres takes place". However, the problem of local shortages of shops was rejected as an issue to be incorporated further into the Structure Plan because, although acknowledged as being of importance, it was believed to be best dealt with in the context of Local Plans. It was suggested that adequate bus services should be maintained "especially in relation to the elderly's access to specialist shopping, recreational, health and if appropriate employment opportunities".

The views of the young and elderly have thus been sought in the planning process of the Structure Plan and much attention has been paid to their reliance on public transport. However, although mention has been made of the fact that many wives do not have access to a car during much of the day, little specific attention has been focused on the problems of access they experience as a result of their carlessness.

8. Hypotheses formulated from the policies of South Yorkshire County Council

This review of the plans of South Yorkshire County Council has clearly shown the importance attached both to the provision of public transport and to the provision of accessibility. This view is summarised in the South Yorkshire County Council and the South Yorkshire Passenger Transport Executive joint policy statement Passenger transport in South Yorkshire (1975) as "the need to provide all members of the community with access to an adequate range of opportunities for work, shopping and leisure activities". In order that public transport might provide accessibility to these facilities, the public transport system itself must be accessible to all those requiring to use it. In Chapters 6 and 7 of this thesis the relationship between the walking and waiting components of bus travel is studied. The walking and waiting times for a sample of points regularly spaced

throughout the Sheffield study area are compared against those obtained from theoretical bus networks in Chapter 6. In Chapter 7 the spatial variation of the walking and waiting times is investigated in relation to various socio-economic characteristics. If the South Yorkshire Structure Plan philosophy of helping the "have-nots" has been successfully implemented then it would be expected that those areas with high proportions of people dependent upon public transport would have a better public transport service, measured here in terms of walking and waiting times, than other areas of the city.

In later chapters of the thesis the implementation of specific Structure Plan policies is investigated. Policy T2 of the Structure Plan as approved by the Secretary of State for the Environment states that "Public transport should, where possible, be provided to assist industrial, commercial, residential, educational, shopping and recreational facilities". The implementation of this policy is studied in Chapter 8 using the example of residential facilities. Thus the hypothesis to be tested can be stated as : "Public transport is being provided to assist the development of residential facilities". The introduction of bus services in the Mosborough area of Sheffield (10km SE of the city centre) is studied and a comparison of changes in bus services in Mosborough and in High Green (10km N of the city centre), where housing development has been less rapid during the study period, is undertaken.

In Chapter 9 the accessibility of district shopping centres in Sheffield is investigated. Structure Plan Policy S2 states that "Provision will be made wherever possible for improvements to the accessibility and environment of district and small town centres", one of the four measures by which this policy will be implemented being "improvements to local bus services where appropriate". The relationship between public transport and shopping facilities is also covered by Policy T2. Changes in bus services centred on five district shopping centres have been monitored in order to test the hypothesis that the accessibility of these centres has been improved through improvements in local bus services.

Accessibility to recreation was a topic which received much attention during the formulation of the Structure Plan and the research is summarized in a technical report (South Yorkshire Structure Plan, 1977). As a result of such research "poor accessibility to sports centres has been identified in many parts of the County as a particular problem (which can be resolved only by improving [bus] services where existing centres are concerned)" (South Yorkshire Structure Plan Written Statement, 1978). Policy R3 indicates that access by public transport will be taken into account when considering potential locations of new recreational facilities. In the form approved by the Secretary of State this policy is stated as "Special consideration will be

given to the provision of new recreational facilities on sites which have, or at a reasonable cost can have, good public transport services or sites which are within convenient walking distance of the majority of their potential users". In Chapter 10 the provision of sports centres in the Sheffield study area is investigated with the aim of assessing whether changes in public transport services and the location of new sports centres have together led to an improvement in the accessibility of these important recreational facilities.

In Chapter 11 the spatial variation in the accessibility of public libraries by bus in the Sheffield study area is investigated. Although the subject of library provision is not specifically mentioned in the South Yorkshire Structure Plan, libraries are an important local level facility to which all members of the community are entitled to have access. This study aims to assess whether present day bus services in Sheffield provide a satisfactory level of access to local facilities.

9. Conclusion

The plans of South Yorkshire County Council have been investigated with respect to the provision of accessibility by public transport. The basic Structure Plan philosophy is one of helping the "have-nots" and people without access to cars are

seen as a large and important group of "have-nots". Thus the need for an effective public transport system is clearly implied. In the Transport Development Plan it is stated that the "passenger transport policies being followed in South Yorkshire have resulted in a major social experiment" (South Yorkshire Passenger Transport Executive, 1978). Although this statement was made in the context of an attempt to justify a larger share of the Transport Supplementary Grant for South Yorkshire, the importance of this "major social experiment" cannot be denied.

According to Structure Plan policies public transport in South Yorkshire is to be provided to assist the development of various facilities and the location of new facilities is to be decided with regard to the ease of access by public transport. Thus the policies of South Yorkshire County Council indicate an intention to mitigate problems experienced by those dependent on public transport, not only through the improvement of public transport itself but also by the careful location of facilities. The hypotheses discussed in Section 8 show how the Structure Plan policies are to be tested in later chapters of this thesis in order to assess whether they have been successfully implemented so as to improve access by public transport to facilities in Sheffield. However, before these hypotheses are tested it is useful to summarise the changes in public transport provision which have taken place in Sheffield and to relate these changes to the policies of South Yorkshire County Council : such an overview is presented in Chapter 5.

CHAPTER 5
AN ANALYSIS OF RECENT CHANGES IN PUBLIC TRANSPORT
PROVISION IN SHEFFIELD

1. Introduction

The aim of this chapter is to assess the extent of changes in the public transport network of Sheffield which have taken place in recent years and to examine whether such changes have been in accordance with the policies of South Yorkshire County Council.

This focus on change might seem to be unexpected because, in common with many urban bus networks, the Sheffield network has been slow to change even in details of its operation. The way in which the bus network has changed only slowly in the Sheffield case can be illustrated by the following examples. First, although bus routes in Sheffield were first numbered in 1926, several routes retain their original number, for example Service 50 (City-Dore) and Service 57 (City-Stocksbridge). Similarly one tram route in Sheffield ran from Walkley through the city centre to Intake and this cross-city route is still in existence as bus Service 95. Third, and perhaps a more significant example is that when trams were in operation in Sheffield, buses ran along the same routes and further out into the newer suburbs, but

passengers could not alight from buses until after the tram termini, and even when tram services were withdrawn this restriction continued in operation through the use of a minimum fares system. For example, although the last tram in Sheffield ran in October 1960 Service 45 to Totley had a minimum fare restriction between the City and Millhouses (the old tram terminus), with access to Millhouses being provided by Services 17, 24 and 26, until 1970. Hall (1977) provides a detailed account of the history of public transport in Sheffield.

Such evidence of slow change has led one critic to assert that "Sheffield's bus services are still in the age of the tram-car" (Star (Sheffield) 19th May 1982), but such an assertion must recognise that the bus network itself reflects a slowly changing pattern of roads and land uses. Furthermore there are good consumer-relation reasons for changing the system slowly; changes of service numbers, routes and even timetables can result in loss of patronage.

It is against this background of little change in the bus industry as a whole and in Sheffield in particular that the policies of South Yorkshire County Council must be judged, because as was discussed in Chapter 4, from its inception in 1974 the County Council has adopted a positive approach to public transport provision and to the improvement of accessibility.

2. Bus services in Sheffield 1962-1982

In order to obtain some indication of the overall changes which have occurred in the provision of bus services in Sheffield over the last twenty-five years, two sets of data were obtained. Firstly the size of the bus fleet in Sheffield as at 1st April 1962, 1972 and 1982 was noted. Secondly the number of buses actually on the road in the built-up area of Sheffield at 11.00 on weekdays was determined using the timetables in operation in 1962 (May-October), 1972 (January-May) and 1982 (June until further notice). This data is presented in Table 5.1.

Table 5.1 Fleet size and buses in operation in Sheffield 1962-1982

Year	Fleet size	Buses in operation at 11.00
1962	856	232
1972	663	239
1982	709	273
Source : personal communication		Source : timetables

The figures concerning the size of the bus fleet show that a large reduction of 23% in the number of buses in Sheffield took place between 1962 and 1972. Between 1972 and 1982 an increase of 7% took place in the size of Sheffield's bus fleet. This

reversal of the trend towards a smaller fleet would suggest that the policies of South Yorkshire County Council have led to an increase in bus services in Sheffield. However, the change in fleet size may not accurately reflect the changes in actual service provision because it takes no account of the efficiency with which each vehicle is used. This is partly remedied by the second set of data which records the number of buses actually on the roads of Sheffield at a specific time.

As shown in the final column of Table 5.1, little change in the number of buses in operation in Sheffield occurred between 1962 and 1972, but a significant increase of 14% took place between 1972 and 1982, in other words since the formation of South Yorkshire County Council. It should be noted that these figures relate to the number of buses in operation at 11.00 weekdays and this increase in service provision could possibly reflect the distribution of vehicle resources across different parts of the day. (Because many buses in operation during the peak periods are not shown in the public timetables, it is not possible to ascertain accurately the number of buses in operation at these times for the three years under consideration.) However, the fact that an increase occurred in both the size of the bus fleet of Sheffield and in the number of buses in operation in Sheffield at 11.00 on weekdays suggests that bus provision in Sheffield has been increased between 1972 and 1982.

In order to appreciate the full significance of the improvement in bus service provision in Sheffield suggested by increases in bus fleet size (of 7%) and in the number of buses in operation at 11.00 (14%) over the ten year period 1972-1982, it is necessary to be aware of the overall decline of urban bus services in the UK in the same period. During this period, the vehicle kilometres (bus and coach) operated by the Passenger Transport Executives and by London Transport Executive decreased by 13%, and the corresponding figure for the Municipal Operators is 9% (Source : Department of Transport, 1983).

The South Yorkshire Structure Plan policies outlined in Chapter 4 stated an intention to improve public transport services in order to facilitate accessibility. Such policies required an increase in the overall level of public transport services. The evidence of Table 5.1 indicates that such an increase in bus service provision in Sheffield has indeed occurred.

3. Developments in bus services 1974-1982

In this section changes which have taken place in the public transport network of South Yorkshire and in particular of Sheffield are analysed at a more detailed level in order to assess how these changes relate to the policies of South York-

shire County Council as outlined in Chapter 4. The data for this section were obtained from Tables 6-9 of Review of passenger transport policy and passenger transport budget 1982/83 (South Yorkshire County Council, no date). Although this report is marked "private and confidential", it forms an appendix to Transport policies and programme 1983-84 (South Yorkshire County Council) and is available on request from the County Council. These tables list for each of the four Districts of South Yorkshire under each year 1974-75 to 1981-82 the services which have been altered together with a note of the nature of the alteration.

The alterations listed in Tables 6-9 of the Review of passenger transport policy... were classified into various types, the types being chosen to relate as far as possible to the policies contained in the South Yorkshire Structure Plan. The types of alteration can be grouped into three broad sections, as listed in Tables 5.2 and 5.3. The first section contains 6 types which are of a positive nature related to the improvement of accessibility to specific facilities or land use types. These types are new development, shopping services, hospitals, industrial areas, rural areas and recreation. These were chosen to reflect the reasons for alterations as given in the Review of passenger transport policy... Other interpretations of the reasons for alterations would have been possible, but the

essential requirement for these six types was that they should correspond to the plans of the County Council and Passenger Transport Executive. The second section consists of three types which indicate improvements to the network, through improved frequency, route extensions and the introduction of new services, but specific reasons for these improvements are not stated. The final 4 types of alteration are of less importance in this context but are included for completeness. They are revisions, replacements, withdrawals/reductions and traffic management. It should be noted that many of the revisions listed are of a minor nature and include extended running time (Service 75/76), revision to Saturday and Sunday services (Services 57/66/67) and withdrawal of joint operator (Service X48).

Each entry was allocated to the first type of alteration applicable. For example, in the Sheffield section for 1978-79 Service X29 was listed as "new service for Mosborough new development" and this has been classified under "new development". In the 1979-80 section Service X29 is listed again, the nature of the alteration being "improved frequency" and this has been classified as "improved frequency", even though it could be assumed that the frequency has been improved to serve the new development. Thus the details given in the Review of passenger transport policy... have been taken as they stand. This enables an assessment to be made of the extent to which the reasons for

the developments in bus services as given by the County Council and Passenger Transport Executive can be related to the policies contained in the South Yorkshire Structure Plan. In particular it should be noted that no attempt was made at this stage to assess the magnitude of the developments by reference to timetables. Where a service has been altered twice in one year and therefore has two entries in the original tables, the alterations to that service are shown separately, for example, the frequency of Service X29 was increased twice during 1979-80 and X29 is therefore listed twice under "improved frequency" for that year.

The results of this analysis are presented in Tables 5.2 and 5.3. Table 5.2 shows the numbers of each type of alteration made in Sheffield and South Yorkshire on a year by year basis. In Table 5.3 the types of alteration to bus services in Sheffield are listed year by year with actual service numbers being shown. Three main features emerge from a study of these tables. Firstly, the public transport network has been expanded in terms of both new routes and improved frequencies to serve new development. The relationship between the development of new residential areas and the timing of the introduction of new and improved bus services is investigated in depth in Chapter 8. Secondly, the substantial number of cases of improved frequency on existing services and the number of extensions to existing

Table 5.2 Alterations to bus services in Sheffield and South Yorkshire 1974-1982 :

number of entries

Type of alteration	Year														Total	
	1974-75		1975-76		1976-77		1977-78		1978-79		1979-80		1980-81		1981-82	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
New development			2	6	3	6	1	1	1	2	1	5	1	2	1	2
Shopping services	1				1	1	1	1		1					2	4
Hospitals								1	1	1				1	1	3
Industrial areas	1	1			1	1									2	2
Rural areas			1			3		2			1			1	6	1
Recreation (inc. rural Derbyshire)					1	1	1	1				1	1	1	1	4
Improved frequency	1		2	4	3	6	2	4		2	6	10	2	2	5	15
Route extensions (inc. positive diversions)	1		1	2	1	4		1	1	2	8	9	2		1	11
New services	1	1	1	1	1	1			1	1			1	1	2	6
Revisions	1	1					4	5		2			2	6	1	7
Replacements	1	2					1	1							2	3
Withdrawals/reductions			1	1					1	1			1	3	1	4
Traffic management	1	2	1	2						1	1				3	5

a : Sheffield b : South Yorkshire

Table 5.3 Alterations to bus services in Sheffield 1974-82 : service numbers

Type of alteration	Year							
	1974-75	1975-76	1976-77	1977-78	1978-79	1979-80	1980-81	1981-82
New development		262,261	1/39,17,261	X30	X29	888	X29	78
Shopping services			15/16	259				
Hospitals					60			
Industrial areas	21		79/89					
Rural areas								255
Recreation (inc. rural Derbyshire)			244	238			210	210
Improved frequency		87,81/82/83	261,254,1	X30,293		X29,207,80,87/88,52,X29		41,80
Route extensions (inc.positive diversions)		500	83/84		34	49,97,95,500,60,47/48,73/265/270/1,96		
New services	Park & Ride	700	26		Night-line		503/4/5	56
Revisions	57/66/67			272,X8,75/76,79/89			Various (Dronfield), X48	
Replacements	24			X7				
Withdrawals/reductions		100			259		270/271	Various (Work services)
Traffic management	Various	Various				Various		

routes indicate that more general improvements have been made to the public transport network since 1974. Finally very little contraction of the bus network has taken place between 1974 and 1982. In Sheffield Service 100 was withdrawn in 1975-76 following the demolition of the Parkwood Springs area, Service 259 a local service in Mosborough was discontinued in 1978-79 and work services were reduced in 1981-82 because of industrial recession.

It is also worth noting the main features of bus service improvements in each of the four Districts as stated in Review of passenger transport policy and passenger transport budget 1982/83. In Barnsley "bus service developments have concentrated primarily on improving accessibility in the more rural areas" (paragraph 6.2.3) and in Doncaster "In the period from 1974 to 1977 a large number of bus service alterations were introduced to serve new development. Subsequently improved frequencies and additional journeys have been the most significant reasons for change" (paragraph 6.3.4). Similarly in Rotherham "throughout the period from 1974 the majority of bus service developments have involved additional journeys or improved frequencies" (paragraph 6.4.3). Over fifty bus service developments were introduced in Sheffield during the period 1974 to 1980 and "by far the most common were extensions of routes to serve additional areas or the introduction of new service, often associated with new development" (paragraph 6.5.4).

The data presented in Table 5.3 have been mapped in Figures 5.1 to 5.3 to illustrate the spatial pattern of improvements to the public transport network of Sheffield since 1974. In Figure 5.1 improvements in bus services to specific facilities or land use types are shown. It should be noted that where the frequency of a service has been increased to serve a specific facility the whole of the route is shown, but where a route has been extended or diverted to serve a specific facility then just the extension or diversion is illustrated. The main feature to emerge is the significance of improvements to the SE of the city centre. Although these improvements were implemented over a number of years to serve the new development at Mosborough, they have resulted in improvements throughout the SE corridor. Improvements have been implemented elsewhere in Sheffield, for example by extra services on the main south western and northern routes. Figure 5.2 shows those services whose frequency has been improved, but without a specific reason for the improvement being stated. Again the broad SE corridor dominates. Figure 5.3 shows the location of route extensions, including positive diversions, and new services where no specific reason was given for the improvement. It was not possible to show several of the services listed in Table 5.3 where these concerned diversions in or near the city centre, presumably to improve access to central facilities. Only 6 services are shown in Figure 5.3 and this is indicative of the fact that most route extensions and new services were introduced to improve accessibility to specific facilities or locations and have therefore been shown in Figure 5.1.

Figure 5.1

Improvements in bus services to specific facilities in Sheffield 1974-1982

Reason for improvement: D new development
H hospital
I industrial area
R recreation
S shopping

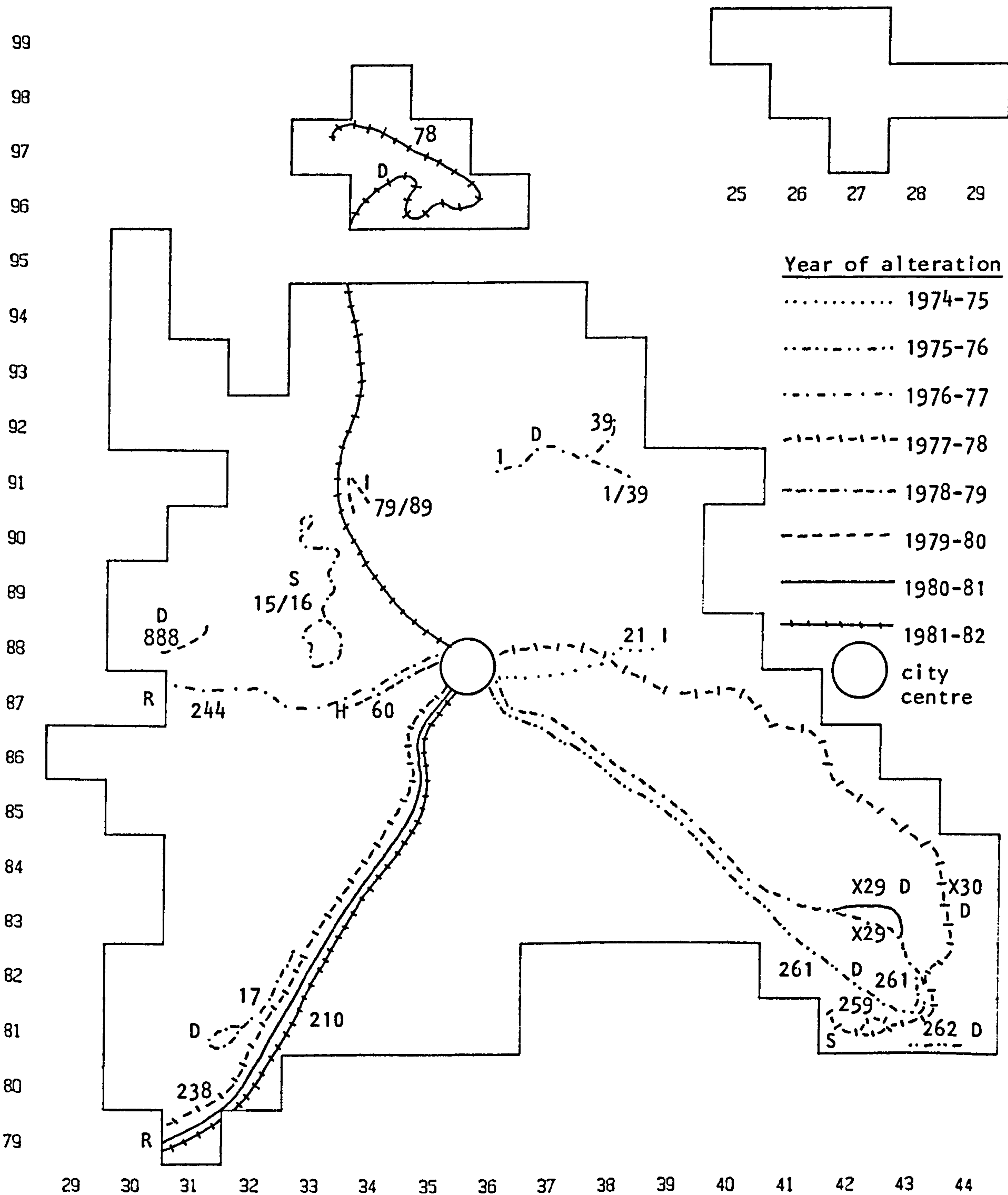


Figure 5.2 Improved frequency of bus services
in Sheffield 1974-1982

No specific reason for improvement was stated in Review of
passenger transport policy and passenger transport budget 1982/83.

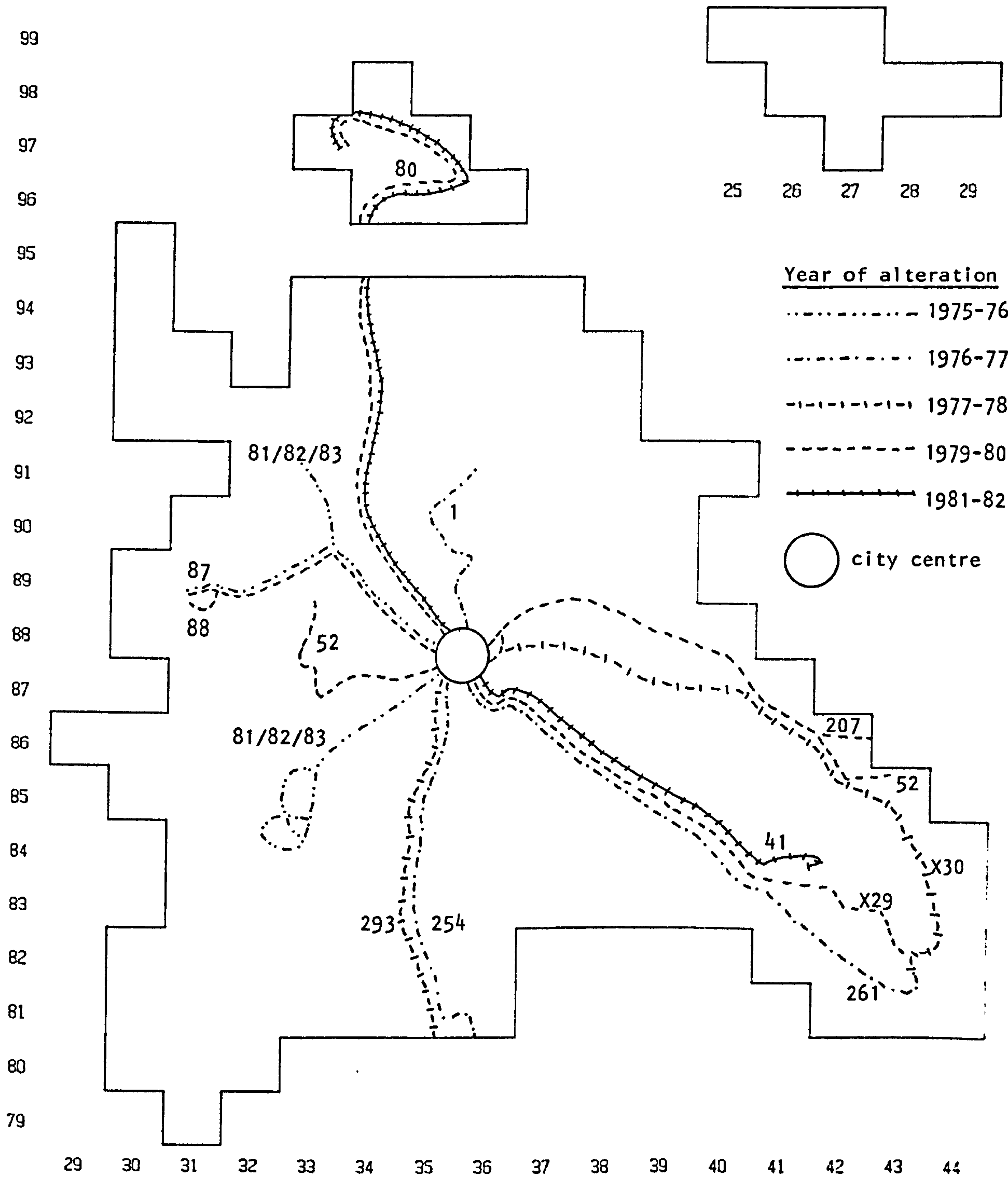
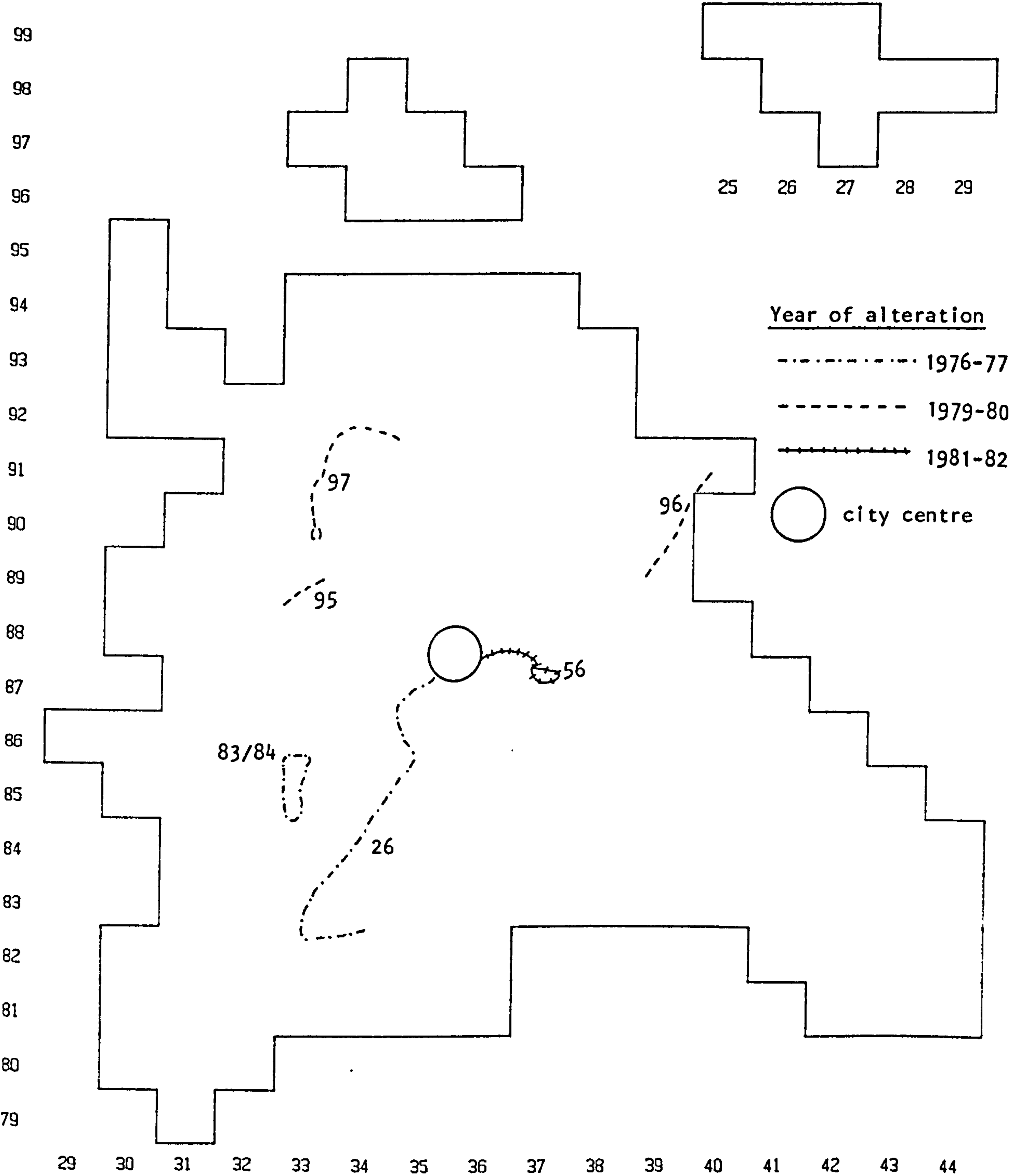


Figure 5.3 Route extensions and new services
in Sheffield 1974-1982

No specific reason for improvement was stated in Review of
passenger transport policy and passenger transport budget 1982/83.



This survey indicates that at least at this broad level of analysis the changes which have been made to the public transport network in Sheffield and throughout South Yorkshire up to 1982 are consistent with policies contained in the Structure Plan. Many of the improvements to bus services in Sheffield have been located in the south eastern sector of the city.

4. Conclusion

It has been shown that in Sheffield bus services have been improved over the last ten years, at least in so far as is indicated by the size of the bus fleet and by the number of buses on the road on weekday mornings. Whilst the public transport network has inevitably evolved slowly over the years, the analysis of specific service alterations has shown that recent changes have been consistent with policies stated in the South Yorkshire Structure Plan. In particular new services and improved frequencies on existing services have been introduced to serve the south eastern sector of Sheffield. Furthermore, "more complex service alterations on a corridor or area-wide basis have been introduced and others are at the planning stage" (South Yorkshire County Council, Transport Policies and Programme 1983-84). Thus, in contrast to declining urban bus services elsewhere in the UK, services in Sheffield continue to be revised and improved.

CHAPTER 6

ACCESS TO BUS SERVICES IN SHEFFIELD : MODELS OF THE WALK AND WAIT ELEMENTS

1. Introduction

If a public transport network and the services operated upon it are to provide adequate access to facilities, then the network and its services must themselves be accessible. The accessibility of the bus network can be assessed by studying two factors, namely the time spent walking from an origin (e.g. place of residence or employment) to the bus stop and the time spent waiting for a bus. These two factors have a significant effect on the accessibility of facilities when measured in terms of total travel time and thus the study of the variability of walking and waiting times is important in the context of public transport accessibility. Variations in walking and waiting times raise two questions :

- (i) Can such variations be explained by a simple model of bus network provision?
- (ii) Does the overall pattern of such variation represent an optimal decision by the operator on the implicit trade-off between route density and service frequency?

In order to examine these two questions a simple bus network model is developed and calibrated for Sheffield. The values obtained from the calibrated model for the walk and wait elements are compared with the measured walking and waiting times at 170 sampling points regularly spaced over the city. In Section 5 the same model is used to estimate the optimal bus network (defined as that which minimises the average walking time plus the average waiting time) for the Sheffield study area given the size of the bus fleet and the average operating speed. The optimal model is then compared with the actual network in terms of route length, average walking time and average waiting time to enable an assessment to be made of the optimality of the route density - service frequency trade-off in Sheffield.

A summary of the variables used in this chapter is provided in Table 6.1.

2. The bus network model

The bus network model used in this study is based on the work of Bly and Oldfield (1974) and Melut and O'Sullivan (1974). Bly and Oldfield's model describes the way in which a bus service network is able to serve its passengers in a large area of constant uniform travel demand. The network, which consists of a square grid of bus routes, is adjusted to provide an optimum

Table 6.1 Variables used in Chapter 6

Symbol	Definition
A	Total area covered by the network
A_1	Domain of elementary grid (Melut and O'Sullivan, 1974)
a	Maximum walking distance, i.e. distance from the centre of the elementary grid to an edge, or half the arc between routes at circumference of radial network
L	Route spacing over a square grid network (Bly and Oldfield, 1974)
N	Size of bus fleet
R	Total route length
r	Radius of radial network
T	Average total time from leaving an origin to boarding a bus
T_{walk}	Average walking time to a bus route
T_{wait}	Average waiting time for a bus
V_b	Operating speed of buses
V_w	Walking speed
θ	Summit angle of elementary grid (Melut and O'Sullivan, 1974) or half the angle between adjacent routes of radial network

service (through the minimisation of the total generalised cost of travel) in terms of the average spacing between routes, the average density of buses per unit area, and the average spacing of bus stops. The model is discussed here in a simplified form in so far as (i) walking distances to bus routes rather than to bus stops are initially considered, (ii) additional waiting time due to buses being fully occupied is not considered, and (iii) the operator's costs are not included. The objective of Melut and O'Sullivan's paper is to compare construction and transportation costs for triangular, orthogonal and hexagonal regular lattices as transport networks serving an unbounded plain, and it is useful here in relation to the distribution of the walk element for the different network grids.

(i) The walk element : distance

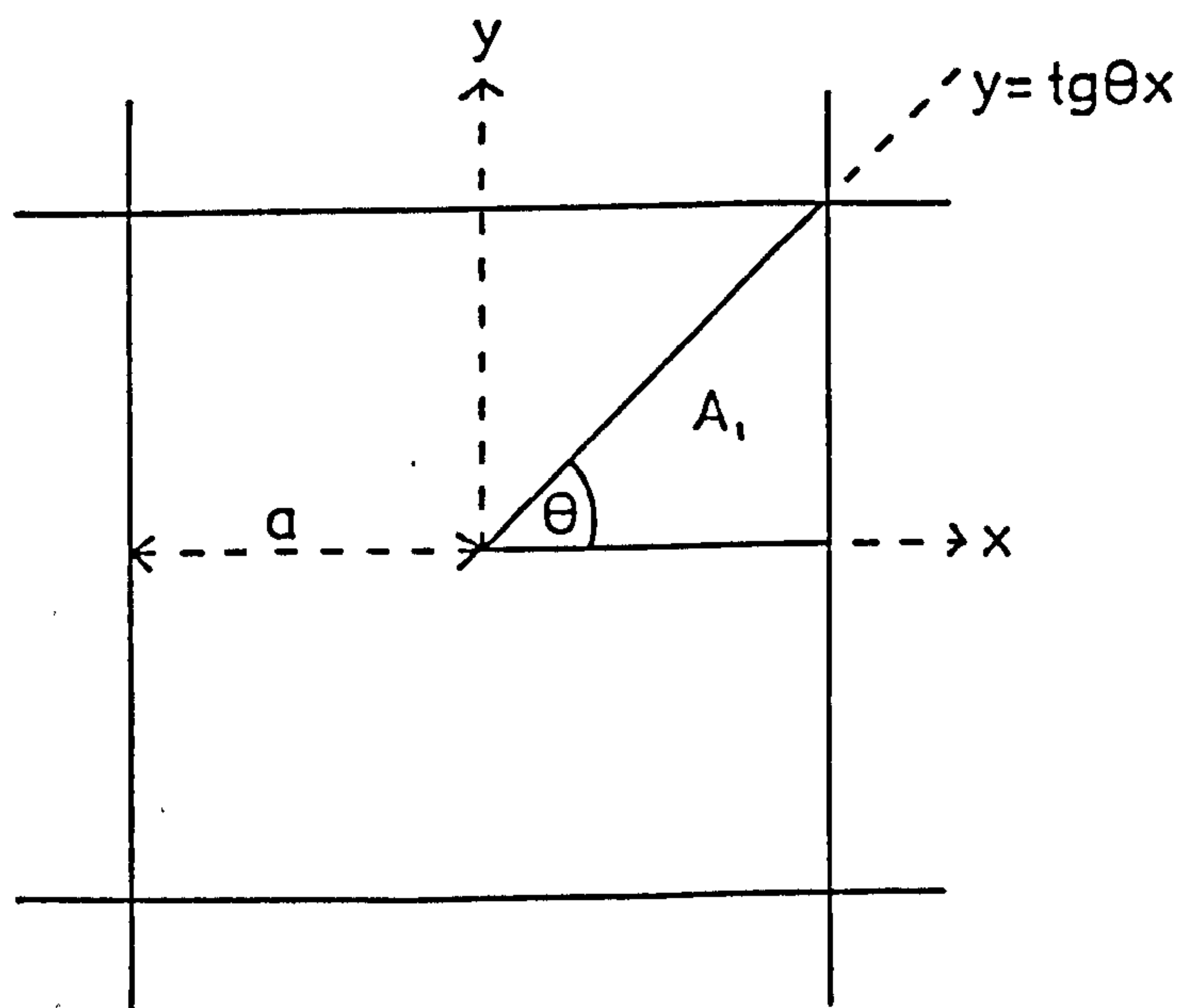
Melut and O'Sullivan show that for the hexagonal, triangular and orthogonal network grids, the maximum walking distance is given by a , where a represents the distance from the centre of the elementary grid to an edge, and the average walking distance is given by $a/3$. This can be proved for the general case by considering the average distance d_m as the expectation of $a-x$ for a uniform density function, where a is the distance from the centre of the elementary grid to the edge on domain A_1 with summit angle θ . This is calculated as :

$$\begin{aligned}
 d_m &= \frac{1}{A_1} \int \int (a-x) dx dy \\
 &= \frac{2}{a^2 \operatorname{tg} \theta} \int_0^a (a-x) \left(\int_0^{\operatorname{tg} \theta x} dy \right) dx \\
 &= \frac{2}{a^2} \int_0^a (a-x)x dx \\
 &= a/3.
 \end{aligned}$$

Figure 6.1 shows the application of the general case to a square grid network.

Figure 6.1

Derivation of the average walking distance to a square grid network



For square, triangular and hexagonal grids it can be shown that $a = A/R$ where A is the total area and R is the route length. The value of R is given by $\frac{1}{2} \times$ the perimeter of each cell \times the number of cells, where the factor of $\frac{1}{2}$ is included as each side is common to two cells and for a sufficiently large number of cells to render the inaccuracies at the periphery insignificant.

For the square network,

$$R = \frac{1}{2} \cdot 8a \cdot A/4a^2$$

$$= A/a$$

$$a = A/R$$

For the hexagonal network,

$$R = \frac{1}{2} \cdot 6a \cdot A/3a^2$$

$$a = A/R$$

For the triangular network,

$$R = \frac{1}{2} \cdot 3 \left(\frac{3a}{\sin 60^\circ} \right) \left(\frac{A}{\frac{1}{2} \frac{3a}{\sin 60^\circ} \cdot 3a} \right)$$

$$a = A/R$$

Thus for the square, triangular and hexagonal grids, the maximum walking distance = A/R and the average walking distance = $A/3R$.

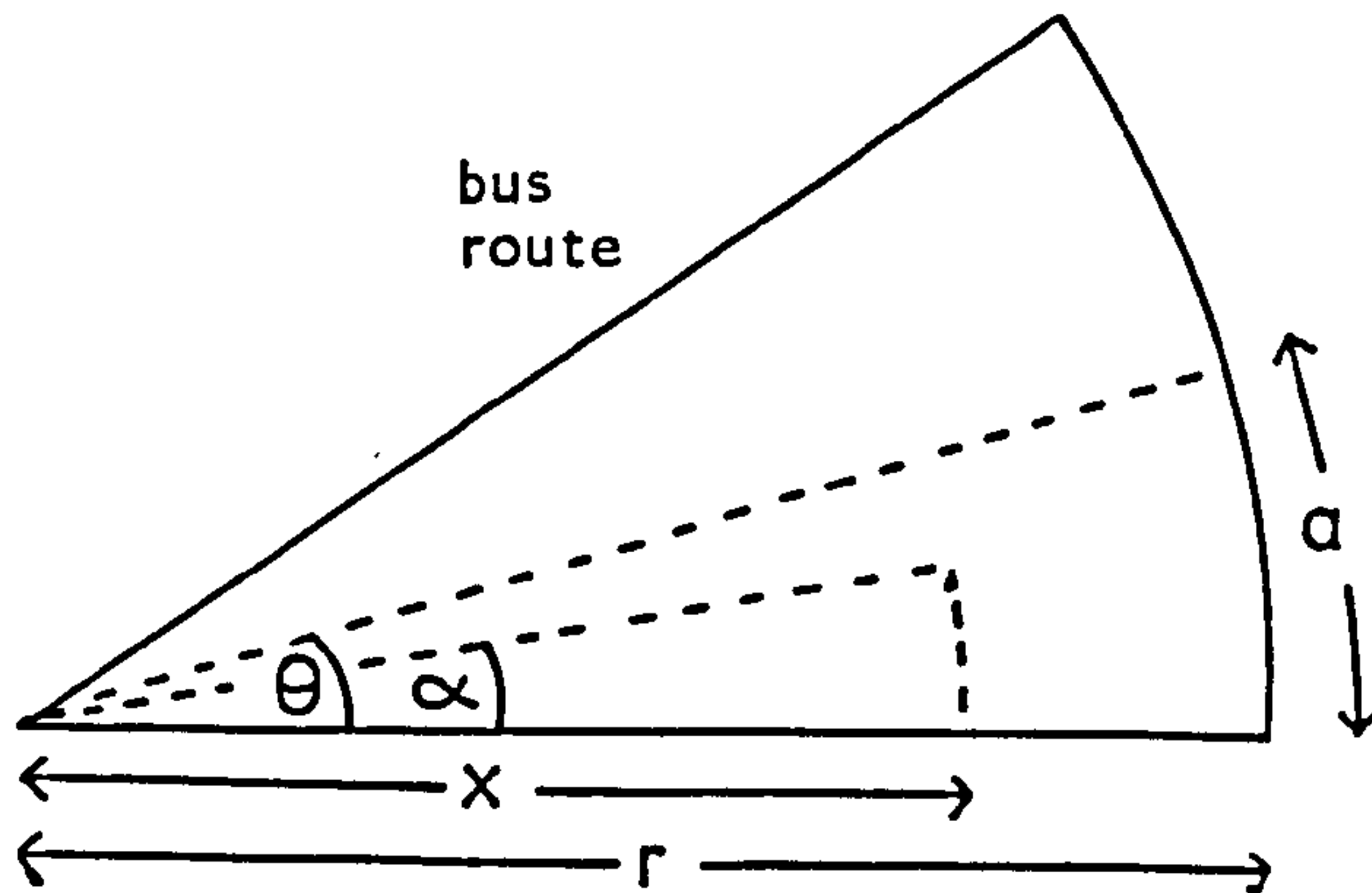
Bly and Oldfield define the route spacing over a square grid network as L , so that the length of each edge is L , and state that the maximum walking distance to the bus route is $L/2$ and the average walking distance is $L/6$. But as it can be shown that $L = 2A/R$ ($R = \frac{1}{2} \cdot 4L \cdot A/L^2$, $R = 2A/L$), the maximum and average walking distances derived are identical to those given by Melut and O'Sullivan.

One further network to be considered is the radial network based on the city centre. As shown in Figure 6.2, the maximum walking distance is given by A/R and the average walking distance by $A/3R$.

Thus if the model is defined as consisting of any of the regular networks discussed here, then the maximum walking distance to a bus route is A/R and the average walking distance is $A/3R$, where A is the area covered by the network and R is the route length. It should be noted that in these network models the walking distances are represented by airline distances and will thus tend to be shorter than actual walking distances. In later sections a route factor is introduced to represent walking distances constrained by the road/footpath network.

(ii) The walk element : time

The average time spent walking to the bus route is given by $A/3RV_w$, where V_w is the walking speed. Thus the choice of an appropriate value for V_w must be carefully considered as it will have a significant effect on the average walking time. Many values for the walking speed can be found in the literature, and although most are based on assumptions, a few are derived from measurements. For example, Lam and Morrall (1982) measured the average walking speed to bus stops in Calgary as 80m/min (4.8km/h). In a study of the Runcorn Busway (Vincent et al, 1976)



$$\text{Maximum walking distance} = a = \frac{2\pi r \theta}{4\pi} = \frac{r \theta}{2}$$

$$\text{now } A = \pi r^2, \quad r = \sqrt{\frac{A}{\pi}}$$

$$\theta = \frac{4\pi}{2 \cdot \text{no. of routes}} = \frac{2\pi}{R}$$

$$a = \frac{2\pi r^2}{2R} = \frac{A}{R}$$

$$\therefore \text{maximum walking distance} = A/R$$

For the average walking distance,

$$\begin{aligned} d_m &= \frac{4\pi}{\pi r^2 \theta} \int_0^r (r-x) \left(\int_0^{\theta} x \cdot \frac{\alpha}{2} d\alpha \right) dx \\ &= \frac{4}{r^2 \theta} \int_0^r (r \cdot x - r \cdot x^2) dx \cdot \frac{\theta^2}{4} \\ &= \frac{\theta}{r^2} \left[\frac{r \cdot x^2}{2} - \frac{x^3}{3} \right]_0^r \\ &= \frac{r \theta}{6} = \frac{1}{6} \sqrt{\frac{A}{\pi}} \cdot \frac{2\pi}{R} \sqrt{\frac{A}{\pi}} \\ &= \frac{A}{3R} \end{aligned}$$

$$\therefore \text{average walking distance} = A/3R$$

an average walking speed of 4.4km/h was recorded for the over 60s, whilst the overall average walking speed, determined from over 3000 observations, was 5.3km/h. Pike and Vougioukas (1982) assumed a walking speed of 5km/h in their public transport accessibility model and this speed is also mentioned in the Department of the Environment Circular 82/73 (1973). Chapman et al (1976) and Danas (1981) assumed a walking speed of 1ms^{-1} (3.6km/h) in their respective studies of bus stop spacing and walking distances to bus stops. A much higher walking speed value of 6km/h is assumed by Forer and Kivell (1981) in a study of space-time budgets.

In this thesis a variety of walking speeds is considered depending on the type of facility being studied. For example, in Chapter 9 where the accessibility of district shopping centres is considered, a walking speed of 3.2km/h (2mph) is used, this low value being chosen to reflect likely walking speeds of people carrying shopping. On the other hand in Chapter 10 it is assumed that people requiring access to sports centres will be reasonably fit and therefore a walking speed of 6.4km/h (4mph) is used. An intermediate value of 4.8km/h (3mph) is used as the walking speed in the study of accessibility to public libraries (Chapter 11). Two values of V_w are considered in this study of access to bus services in Sheffield, namely 3.5km/h and 5.0km/h.

(iii) The wait element

Consider N buses distributed equally over any regular network covering area A with route length R and operating at speed V_b . The distance separating buses moving in the same direction along any route is $2R/N$, the factor of 2 being included because buses operate in both directions. The headway (the time separating the buses) is $2R/NV_b$. Defining the average waiting time as being equivalent to half the headway,

$$\text{average waiting time} = \frac{R}{NV_b}.$$

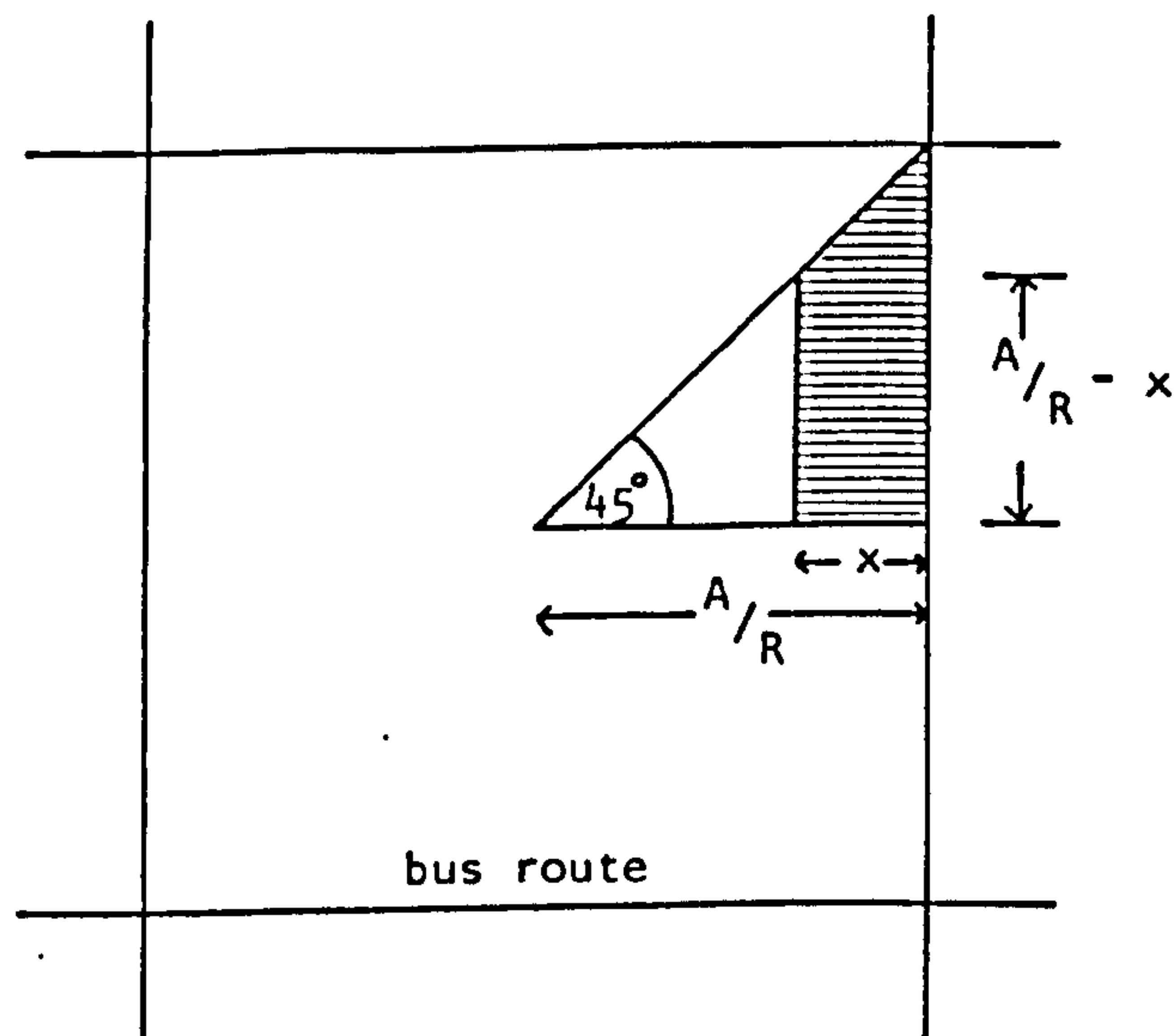
As Furth and Wilson (1981) point out the definition of the average waiting time as being half the average headway is based on random passenger arrivals and assumes that headways are regular and that buses are not operating close to capacity. Many surveys have found, however, that actual passenger waiting times are on average smaller than half the average headway, particularly for longer headways as passengers do not arrive at the bus stop randomly through time, but arrive in relation to anticipated bus arrivals. For example, in a survey in Greater Manchester, Seddon and Day (1974) found that passenger arrivals are random only up to a mean bus headway of about 10 minutes, and similarly Lam and Morrall (1982) found that in Calgary the average waiting time is approximately equal to half the headway for headways under 10 minutes, whilst for longer headways the

average waiting time tends to be about 11 minutes. However, the definition of the average waiting time as being equal to half the headway does provide a meaningful measure of the level of service provision.

(iv) The explanatory bus network model

In order to assess whether the walk element of the simple bus network model adequately explains the walking times measured for the study area, it is necessary to compare not only the average walking distances but also the distribution of these distances. For the square grid this distribution can be determined from the proportion of the shaded area to the whole triangular area as x varies from 0 to A/R as shown in Figure 6.3.

Figure 6.3 Distribution of walking distances
in a square grid network



Proportion of walking distances $\leq x$

$$= \frac{1 - (A/R - x)^2}{(A/R)^2}, \text{ as } x \text{ varies from } 0 \text{ to } A/R.$$

For the wait element, frequency is defined as being equal over all routes in the model so that the single value R/NV_b gives the average waiting time for all points on the network model. Thus it is possible to compare only the average waiting time of the model with the waiting times of the Sheffield data.

(v) The normative bus network model

The bus network model described in Sections 2i to 2iii can be used as a normative model yielding the values that minimize the average total time elapsing from leaving an origin until boarding a bus, given a fixed number of buses. The average total time comprises the average time spent walking to the bus route and the average time spent waiting for a bus, i.e.

$$\begin{aligned} T &= T_{\text{walk}} + T_{\text{wait}} \\ &= \frac{A}{3RV_w} + \frac{R}{NV_b} . \end{aligned}$$

To identify the optimal system this equation is differentiated with respect to R ,

$$\frac{dT}{dR} = - \frac{A}{3R^2V_w} + \frac{1}{NV_b} .$$

A turning point occurs when $\frac{dT}{dR} = 0$, i.e. when

$$\frac{A}{3R^2V_w} = \frac{1}{NV_b} , \quad R = \pm \sqrt{\frac{ANV_b}{3V_w}} .$$

As R must be positive, the negative solution is ignored.

When R is $< \sqrt{\frac{ANV_b}{3V_w}}$, $\frac{dT}{dR}$ is negative.

When R is $> \sqrt{\frac{ANV_b}{3V_w}}$, $\frac{dT}{dR}$ is positive.

This indicates that the turning point is a minimum. Thus a minimum occurs when

$$\frac{A}{3R^2V_w} = \frac{1}{NV_b}, \quad \therefore \quad \frac{A}{3RV_w} = \frac{R}{NV_b},$$

i.e. $T_{\text{walk}} = T_{\text{wait}}.$

This equality is a necessary and sufficient condition for network optimality, given the size of the bus fleet (N) and the average operating speed (V_b). Thus in order to minimize the average total time spent walking to the bus route and waiting for a bus, the density of the network and the frequency of services on it should be such that overall the average walking time and the average waiting time are equal. This mathematical result is slightly surprising as there is no intuitive reason to suppose such a relationship (for similar results see Holroyd, 1967, and Bly and Oldfield, 1974).

3. Data collection

The simple bus network model described in Section 2 will be used in this study of the accessibility of the public transport network firstly as an explanatory model and secondly as a norm-

ative model. In the first case the model will be calibrated for Sheffield and the walk and wait elements compared with walking and waiting times measured over the city. Using the model normatively, the route length required to achieve optimality for the model when calibrated for Sheffield will be compared with actual route length over the study area. These analyses require two sets of data, namely (i) values for the variables of the bus network model outlined in Section 2 such that the model can be calibrated for Sheffield, and (ii) values of the walk and wait elements obtained from a set of sampling points regularly spaced over Sheffield.

(i) Calibration of the bus network model

The bus network model discussed in Section 2 contains variables relating to (1) the area covered by the network, (2) the route length, (3) the number of buses operating over the network, (4) the speed of the buses, and (5) the walking speed. In order to compare this model with the walk and wait data collected over Sheffield values had to be assigned to these variables and this was achieved as summarised below.

1) A : area : 170km²

Composed of the kilometre squares surrounding each of the 170 1km National Grid intersections forming the sampling framework for the Sheffield study area (see Section 3ii).

2) R : route length : 391km

Obtained by transferring bus routes from the April 1982 Route Map to the A-Z 4" to 1 mile map for the study area and measuring the total length with a map measurer. (When the model is used normatively the value of R is determined by the model itself.)

3) N : number of buses : 273

Obtained by counting the number of buses in operation in the study area at 11.00 weekdays from the June 1982 timetable. From a diagram in South Yorkshire Transport's Facts and Figures (1983) the total number of buses in service in Sheffield at 11.00 Monday to Friday appears to be approximately 320. However, the value of 273 is to be preferred as it relates specifically to the study area.

4) V_b : bus speed : 17.7km/h

Average value obtained from measurements undertaken in the study of the accessibility of district shopping centres and based on 64 measurements (see Chapter 9).

5) V_w : walking speed : 3.5km/h and 5.0km/h

These values were chosen because the range they cover is consistent with values of walking speed used in several other studies, as outlined in Section 2ii.

(ii) The measurement of walk and wait elements in Sheffield

The sampling framework for the collection of walk and wait values relating to the accessibility of the public transport network of Sheffield was based on the National Grid. A sampling point was defined as lying at the intersection of 1km grid lines if the kilometre square of which the intersection formed the midpoint contained housing in Sheffield, in so far as could be judged from the O.S. 1:50000 map and the A-Z 4" to 1 mile map. Six points which qualified under this definition were excluded because of their primarily rural nature (2793, 2796, 2792, 2692, 2897 and 2984). The sampling framework thus consisted of 170 points evenly spaced over the Sheffield study area.

The walk element was calculated by measuring the distance from the sampling point to the nearest bus route to Sheffield city centre using a map measurer on the A-Z 4" to 1 mile map and moving from the point directly to the nearest road or footpath in the direction of the bus route and then along the road/footpath network to the route. Distances were measured to the nearest 1/8th mile (0.20km). Distances to bus routes rather than to bus stops were measured for practical reasons.

The wait element was based on half the average headway of buses along the route to Sheffield city centre between 10.00 and 12.00 Monday to Friday (i.e. wait = $120/2n$ minutes, where n =

number of buses between 10.00 and 12.00). As discussed in Section 2iii, the definition of the average waiting time as being equal to half the average headway provides an adequate measure of the level of service provision. The timetable which came into operation in June 1982 was used in conjunction with the April 1982 Route Map. Limited stop services were excluded (except in areas where they operate without restriction) as were services subject to minimum fares. For circular services based on the city centre, only buses in the direction most direct to the city centre were included. On the outer circular routes (Services 2 and 59) buses were included only when on a reasonably direct run into the city centre (i.e. from Crosspool for Service 2 and Ecclesall Road South for Service 59).

One problem encountered in applying this methodology occurred when the nearest bus route happened to have an infrequent service whilst a slightly more distant bus route had a more frequent service. In reality it is likely that some trade-off between the walk and wait elements would occur in such a situation. Therefore if the waiting time at the nearest bus route exceeded 12 minutes, more distant bus routes were studied to find the route which provided the minimum walking plus waiting time combination assuming a walking speed of 4.8km/h. The choice of 12 minutes as the critical waiting time value was to some extent arbitrary, but the use of a smaller value would have involved much work as more potential trade-offs would have required consideration. For 39 sampling points two walking distance values were thus recorded :

- (i) the distance to the nearest bus route, and
- (ii) the distance to the route which provided the lowest walking plus waiting time combination.

The walking and waiting time values for Sheffield are based on a regular sampling framework at 1km intervals. In order to assess whether this framework is sufficiently representative an analysis was undertaken in connection with the study of the accessibility of sports centres by public transport and is presented in Chapter 10 Section 4ii. The variables used in the model of the Sheffield bus network, namely A, R, N, V_b , have been measured as outlined above, but the estimates used are recognised to be potentially in error. Wherever the results presented in the following sections appeared as though they might be sensitive to these estimates, cross-checks have been made. For example, the value assigned to V_b (bus speed) was 17.7km/h, this being based on the average of 64 measurements of bus services around five district shopping centres in Sheffield. A cross-check was made by weighting these measurements according to the frequency of the bus services between 10.00 and 12.00. This gave a value for V_b of 17.3km/h which would have made very little difference to the results presented below.

4. The explanatory bus network model

Here the simple bus network model outlined in Section 2 is calibrated for Sheffield using the values outlined in Section 3i, including the measured value of 391km for the route length, R .

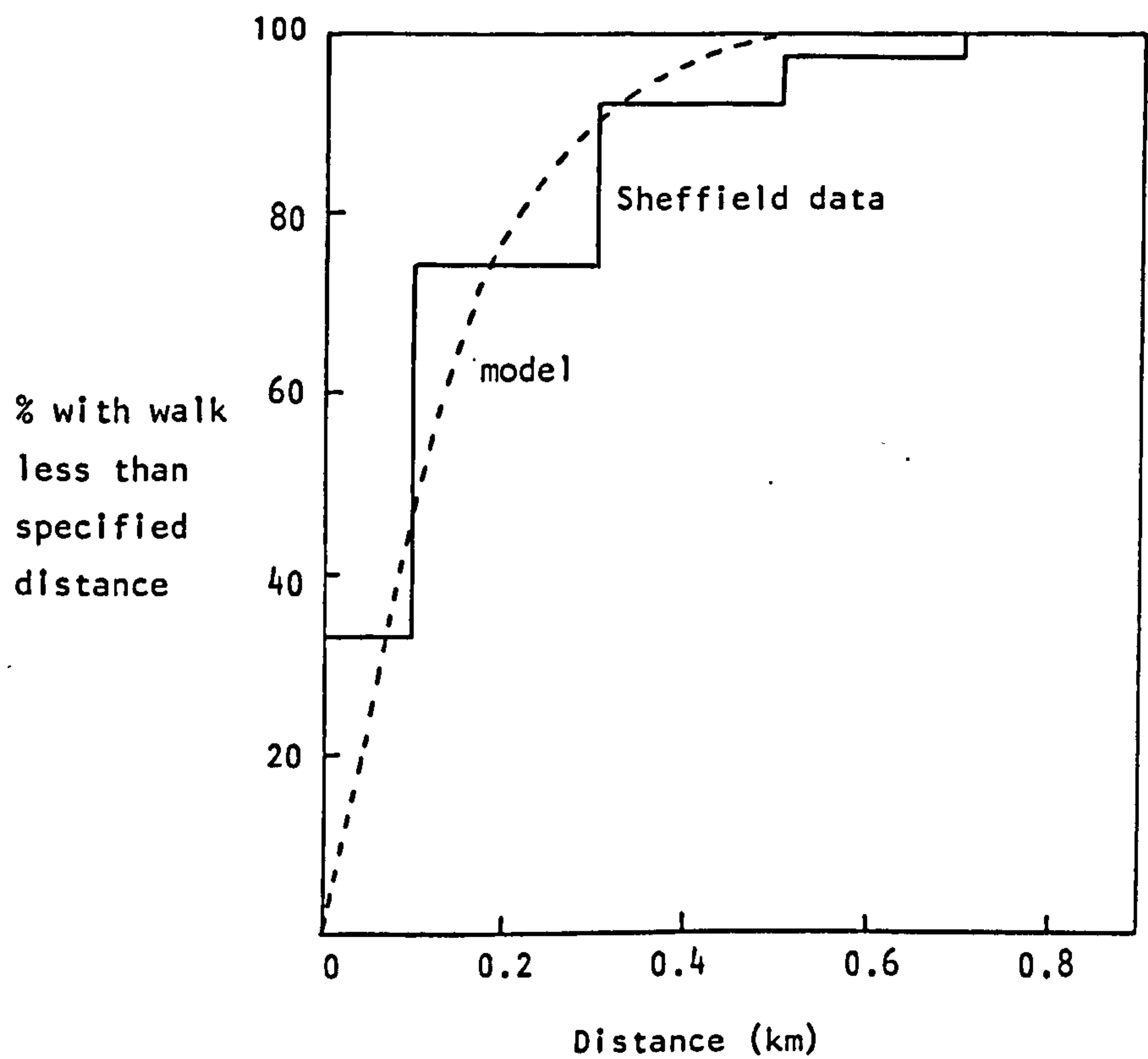
(i) The walk element

The average walking distance for the model is $A/3R$ which when calibrated for Sheffield equals 0.14km. For the Sheffield data the average walking distance is 0.21km (s.d.0.20) using nearest routes (and 0.31km using those routes giving the lowest walking plus waiting time combination). The Student's t test was used to assess whether the difference in these values is statistically significant. The value of t was 4.56 which is significant at the 95% level. Thus it appears that the average walking distance for the Sheffield data is significantly greater than that of the model.

In addition to comparing the average walking distances, a statistical comparison can be made of the distributions of the walking distances using the Kolmogorov-Smirnov test. Figure 6.4 shows the distribution of walking distances for the Sheffield data (nearest route) and the model. The distribution for the model relates to a square grid network and was calculated as outlined in Section 2iv. The Kolmogorov-Smirnov test indicates that at the 95% probability level, the difference in the distribution of walking distances for the Sheffield data and the square grid network is significant.

Figure 6.4

Distribution of walking distances:
Sheffield data and model



Distance	0-0.1	0-0.3	0-0.5	0-0.7	0-0.9
Sheffield	0.33	0.74	0.92	0.97	1.0
Model	0.41	0.91	1.0	1.0	1.0
Difference	0.08	0.17	0.08	0.03	0

Kolmogorov - Smirnov test

Test statistic : 0.17

Critical value at 95% level : 0.104

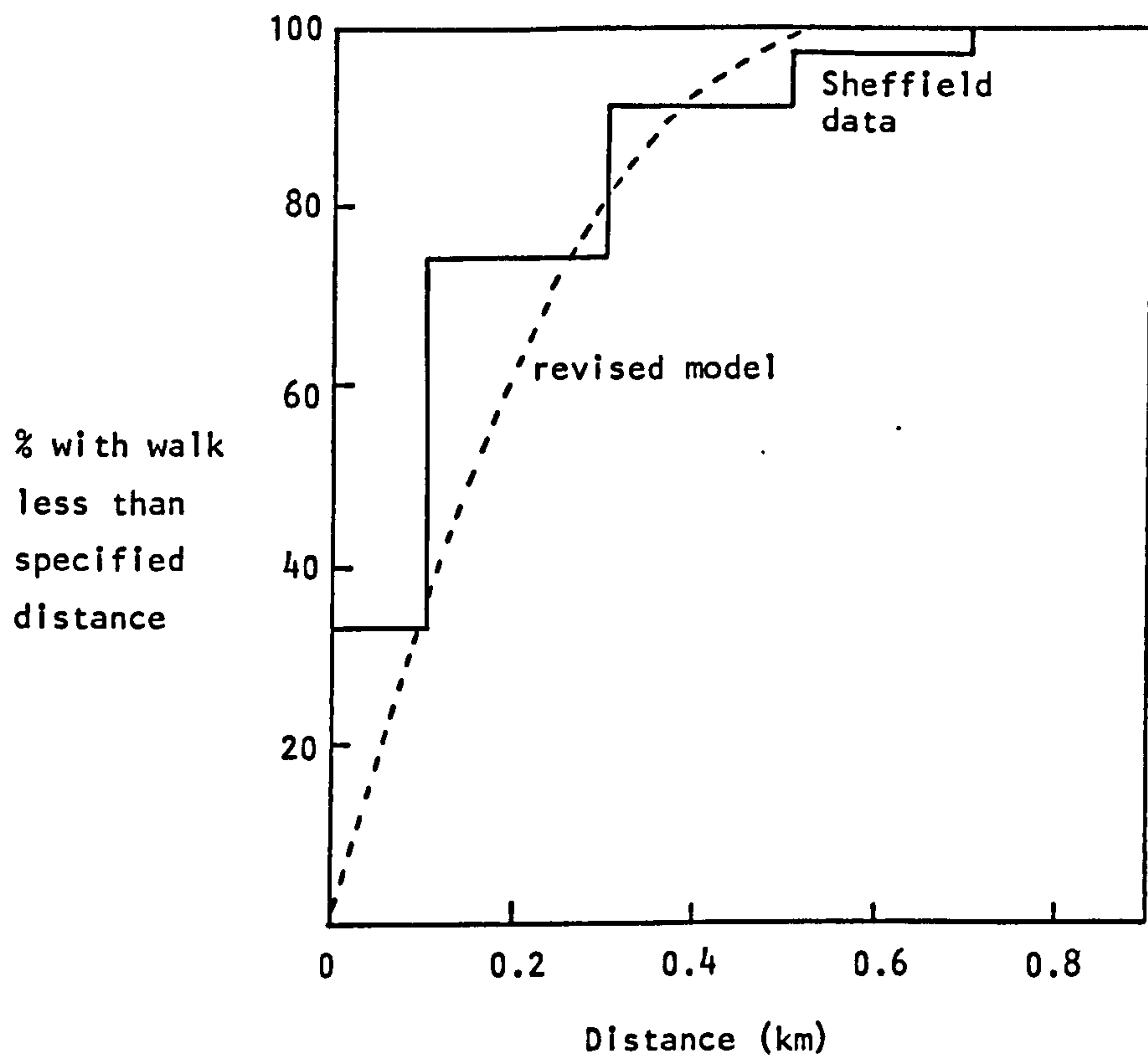
However, the explanatory model can be refined by the incorporation of a route factor to account for the fact that actual walking distances are constrained by the road/footpath network and are thus greater than straight line distances. In order to correct the straight line distances of the model to reflect corresponding distances along the road/footpath network a route factor of 1.29 was used. This value was derived from the ratio between the walking distance and the straight line distance for a sample of 10% of the 170 sampling points. In his study of accessibility to bus services in Greenwich, Morphet (1979) uses a similar route factor value of 1.27. The average walking distance for the model is now $\frac{1.29A}{3R}$ which when calibrated for Sheffield equals 0.18km. The Student's t test indicates that this value is not significantly different from that of the Sheffield data (test statistic = 1.96, critical value at 95% level = 1.96).

Figure 6.5 shows the distribution of walking distances for the Sheffield data and the revised model. The Kolmogorov-Smirnov test can again be used to assess the significance of the differences in the distribution. This test indicates that the differences in the distribution of walking distances for the Sheffield data and the revised model are not significant.

Figure 6.5

Distribution of walking distances:

Sheffield data and revised model



Distance	0-0.1	0-0.3	0-0.5	0-0.7	0-0.9
Sheffield	0.33	0.74	0.92	0.97	1.0
Revised Model	0.33	0.79	0.99	1.0	1.0
Difference	0	0.05	0.07	0.03	0

Kolmogorov - Smirnov test

Test statistic : 0.07

Critical value at 95% level : 0.104

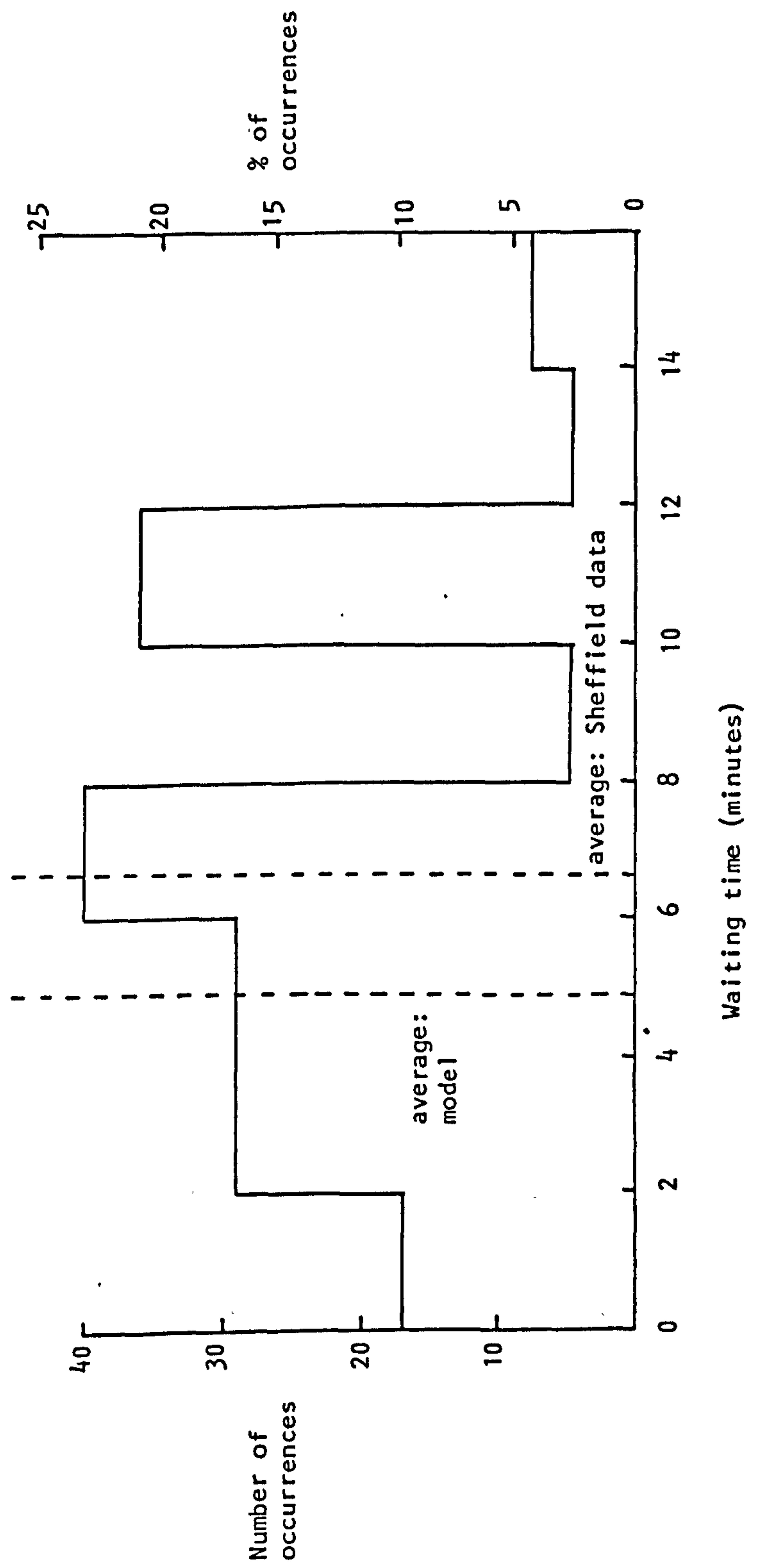
(ii) The wait element

For the bus network model the average waiting time is R/NV_b , which when calibrated using the values outlined in Section 3i equals 4.86 minutes. For the Sheffield data the average waiting time is 6.66 minutes (s.d.3.54). To establish whether these values are significantly different the Student's t test was used. The value of t was 6.65 which is significant at the 95% level. Therefore the average waiting times for the Sheffield data and the bus network model are significantly different.

The distribution of the waiting times for the Sheffield data is illustrated in Figure 6.6. The pattern of the distribution indicates that the frequency of bus services in Sheffield is such that average waiting time values fall into two broad groups, less than 8 minutes and 10 minutes or over. (Few points have waiting times of between 8 and 10 minutes as no value within the associated frequency range of over 16 minutes and under 20 minutes divides equally into 60, so that it is not possible to run buses at regular times past the hour as is preferred for timetabling purposes.)

It has been shown that the average waiting time for the Sheffield data is significantly greater than that of the model. This discrepancy arises at least in part because the model does not incorporate an element of unequal frequency. For the model

Figure 6.6 Distribution of waiting times: Sheffield data



frequency is defined as being equal on all routes; obviously this is a simplification of reality where frequencies must be related to demand along each route. Indeed the extent of the variation in the waiting time values, which are directly related to frequency, is illustrated in Figure 6.6 for the Sheffield data. The behaviour of the model under conditions of unequal frequency can be studied by assigning a set number of buses to a few routes in different ways.

Suppose there are 6 routes each of 2km length with 12 buses to be assigned to these routes. For the model the average waiting time is $R/NV_b = 3.39$ minutes ($R=12\text{km}$, $N=12$, $V_b=17.7\text{km/h}$). The buses can now be assigned to the routes, the waiting time for each route can be calculated using R/NV_b with $R=2\text{km}$, and the average of these times can be found. This process is analogous to the data collection method, assuming each route is used once in the sampling procedure. If each of the 6 routes has 2 buses on it then the waiting time equals 3.39 minutes, as expected. However, if 1 route has 1 bus assigned to it, 4 routes have 2 buses and the 6th route has 3 buses, then the waiting time is 3.77 minutes. If the distribution is even more unequal with 2 routes having 1 bus, 2 routes having 2 buses and 2 routes having 3 buses, then the waiting time is increased to 4.14 minutes. Finally if 3 routes have 1 bus each assigned to them and 3 routes have 3 buses each then the waiting time is even greater at 4.52 minutes. These figures are summarised in Table 6.2.

Table 6.2 Summary of allocation of 12 buses
to 6 routes of length 2km

Bus allocation	Average waiting time (minutes)		
1 bus on 1 route	6.78		
2 buses on 1 route	3.39		
3 buses on 1 route	2.26		
	Model	Data collection method	Differ- ence
2 buses on each of 6 routes	3.39	3.39	0
1 bus on 1 route, 2 buses on 4 routes, 3 buses on 1 route	3.39	3.77	0.38
1 bus on 2 routes, 2 buses on 2 routes, 3 buses on 2 routes	3.39	4.14	0.75
1 bus on 3 routes, 3 buses on 3 routes	3.39	4.52	1.13

The model thus minimizes the average waiting time for a given number of buses through the assumption that the buses are equally distributed over the network. This explains at least in part the significant difference between the average waiting time of the Sheffield data and of the model.

(iii) Conclusion : explanatory model

The findings of this section are summarised in Table 6.3.

Table 6.3 Comparison of the Sheffield data and the explanatory model

	Average walking distance	Average waiting time
Sheffield data	0.21km (nearest route) 0.31km (lowest walk plus wait time)	6.66 minutes
Explanatory model :		
Simple	0.14km	4.86 minutes
Simple + route factor	0.18km	4.86 minutes

When the simple bus network model is modified to include a route factor of 1.29 to represent walking distances confined to the road/footpath network, the differences between the distributions of walking distances for the Sheffield data and for the model are not statistically significant. However, the difference between the average waiting time for the Sheffield data and the model is significant, with the value for the Sheffield data being 37% greater than that of the model. This discrepancy is caused at least in part by the assumption in the model of equal frequencies along all routes : but in reality frequency varies in relation to demand along each route. Thus although the revised model adequately accounts for the walking time to bus routes in Sheffield, it has a smaller average waiting time value than that of the Sheffield data because of the assumption of uniform bus frequencies, even if there were no other sources of variation.

5. The normative bus network model

(i) The simple model

In Section 2v it was shown that the bus network model is optimized in terms of minimizing the average total walking plus waiting time when the average walking time and the average waiting time are equal :

$$\frac{A}{3RV_w} = \frac{R}{NV_b} .$$

This condition occurs when $R = \sqrt{\frac{ANV_b}{3V_w}}$.

Using the values stated in Section 3i, $R = 280\text{km}$ when $V_w = 3.5\text{km/h}$ and 234km when $V_w = 5.0\text{km/h}$. This gives average walking and waiting times of 3.47 minutes and 2.91 minutes at walking speeds of 3.5km/h and 5.0km/h respectively.

The bus route length over the Sheffield study area was measured at 391km, significantly greater than the values obtained for the normative model. This suggests that the bus network in Sheffield is sub-optimal with excessive route length in relation to the number of buses operating on it, leading to slightly shorter walking times at the expense of longer waiting times : for the Sheffield data the average walking time is 3.60 minutes at 3.5km/h and 2.52 minutes at 5.0km/h to the nearest routes (and 5.29 minutes and 3.71 minutes to those routes which provide the lowest walking plus waiting time combination) whilst the average waiting time is 6.66 minutes.

However, these conclusions are only true if this crude normative model is adopted. The model can be refined in two ways. Firstly a route factor can be introduced so that walking times reflect distances along the road/footpath network rather than straight line distances. Secondly a constant can be incorporated into the model to reflect the average walking distance along a bus route to the nearest bus stop.

(ii) Model with route factor

As outlined in Section 4i, a route factor of 1.29 was found to be appropriate for this study. Incorporating the route factor into the walk element of the normative model and putting $T_{\text{walk}} = T_{\text{wait}}$ for optimality,

$$\frac{1.29A}{3RV_w} = \frac{R}{NV_b}$$

$$R = \sqrt{\frac{ANV_b}{3V_w} \cdot 1.29}$$

$$R = 318\text{km} \quad \text{when} \quad V_w = 3.5\text{km/h}$$

$$\text{and} \quad R = 266\text{km} \quad \text{when} \quad V_w = 5.0\text{km/h}.$$

When $R = 318\text{km}$ and $V_w = 3.5\text{km/h}$ the average walk and wait elements for the model are 3.94 minutes. When $R = 266\text{km}$ and $V_w = 5.0\text{km/h}$ the average walk and wait elements for the model are 3.30 minutes. The walking time value for the model is greater than the Sheffield value to the nearest route when $V_w = 3.5\text{km/h}$

or 5.0km/h. However, the model predicts lower walking and waiting times than those of the Sheffield data when the walking distance to routes giving the lowest walking plus waiting time combination is used. Thus the bus route length in Sheffield is greater than that predicted by the revised model and this sub-optimality results in low frequencies and high waiting times, with no compensating decrease in walking times.

(iii) Model with route factor and distance to bus stops

Walking distances have now been adjusted for the model to reflect distances along the road/footpath network. However, distances still relate to bus routes rather than to bus stops and in order to compare walking times with waiting times more realistically, it is necessary to add a component representing the average walking distance along the bus route to the bus stop. If the distance between bus stops is d , then the average walking distance along the route to a stop is $d/4$. The average distance between stops was found to be 0.3km for a sample of routes in Sheffield. This is slightly less than the Department of the Environment (1973) recommended spacing of bus stops in urban areas of 2 to 3 to the kilometre. Taking the average distance between stops to be 0.3km the average walking distance along a bus route to the nearest stop is therefore 0.075km. Optimality of the model can now be stated as

$$T_{\text{walk}} = T_{\text{wait}}$$

$$\frac{1.29A}{3V_w R} + \frac{0.075}{V_w} = \frac{R}{NV_b}$$

$$\frac{R^2}{NV_b} - \frac{0.075R}{V_w} - \frac{1.29A}{3V_w} = 0$$

This can be solved for R to give a value of 374km when $V_w = 3.5\text{km/h}$ and 304km when $V_w = 5.0\text{km/h}$. It will be noted that the route length of 374km obtained from the revised normative model with a walking speed of 3.5km/h is similar to the route length of 391km measured for the study area.

In order to compare the average walking and waiting times for the Sheffield data more realistically the constant 0.075km must similarly be added to the average walking distance to a bus route so that the resulting figure represents the average walking time to a bus stop. This gives an average walking time of 4.89 minutes using nearest routes and 6.58 minutes using those routes giving the lowest walking plus waiting time combination when $V_w = 3.5\text{km/h}$. At a walking speed of 5.0km/h the values are 3.42 minutes and 4.61 minutes respectively. For the model, when $R = 374\text{km}$ and $V_w = 3.5\text{km/h}$ the average walking and waiting times are 4.64 minutes, less than the corresponding values for the Sheffield data. When $R = 304\text{km}$ and $V_w = 5.0\text{km/h}$ the average walking and waiting times are 3.78 minutes. The only value for

the corresponding Sheffield data smaller than this is that of 3.42 minutes for the average walking time using nearest routes; the other walking time value and the average waiting time are significantly larger (4.61 minutes and 6.66 minutes respectively).

It has been shown for the simple bus network model that optimal bus services exist when the average walking time and the average waiting time are equal. Equality of these elements is exhibited in the Sheffield data using routes giving the lowest walking plus waiting time combination when the walking time is adjusted to reflect access to bus stops rather than to bus routes and when a walking speed of 3.5km/h is used (average walking time = 6.58 minutes, average waiting time = 6.66 minutes).

(iv) Conclusion : normative model

The findings of this section are summarized in Table 6.4.

According to the simple bus network model described in Section 2, optimality of the model in terms of minimising the average total time spent walking and waiting for a bus occurs when the average walking time and the average waiting time are equal. In order to study the degree of optimality of bus services in Sheffield, the required route length R for a given bus fleet N was derived. It was found that the optimal R was substantially less than the actual route length measured for the

Table 6.4 Comparison of the Sheffield data and the normative model

	Walking Speed km/h	Average Walk minutes		Average Wait minutes	Route Length km
		A	B		
Sheffield data	3.5	3.60	5.29	6.66	391
	5.0	2.52	3.71	6.66	391
Sheffield data + bus stop	3.5	4.89	6.58	6.66	391
	5.0	3.42	4.61	6.66	391
Normative model :					
Simple	3.5	3.48		3.46	279
	5.0	2.91		2.91	234
Simple + route factor	3.5	3.94		3.94	318
	5.0	3.30		3.30	266
Simple + route factor + bus stop	3.5	4.64		4.64	374
	5.0	3.79		3.77	304

A : average walking time to nearest routes

B : average walking time to routes giving lowest walking
time plus waiting time combination

study area. The incorporation of a route factor of 1.29 into the walking time equation and the addition of a constant to represent the average walking time along the bus route to the nearest stop substantially improved the match between the Sheffield system and the model.

The value of R closest to the route length measured for the study area occurred when the above factors were incorporated into the model and a walking speed of 3.5km/h was used ($R = 374\text{km}$ for the model, measured route length = 391km). This suggests that the length of the bus network over Sheffield is almost optimal in relation to the number of buses operating on the network at 11.00 weekdays when a fairly low walking speed is assumed. This suggestion of optimality is reinforced by the data collected on walking and waiting times in Sheffield; the average walking time to the nearest bus stop at a walking speed of 3.5km/h is 6.58 minutes (using those routes providing the lowest walking plus waiting time combination) and the average waiting time is 6.66 minutes. The low walking speed required for optimality suggests that bus services in Sheffield are best meeting the needs of the elderly and those with young children. This is consistent with the South Yorkshire Structure Plan philosophy of helping the "have-nots".

6. Summary and implications

Access to bus services in Sheffield has been investigated in terms of the walking time and waiting time for a sample of 170 points. These measurements have been compared with the average walking and waiting times derived from a bus network model with variables calibrated to represent bus services over Sheffield.

The distributions of the walking distances for the Sheffield data and the explanatory model are not significantly different when a route factor of 1.29 is incorporated into the model to represent walking distances confined to the road/footpath network rather than straight line distances. The average waiting time for the Sheffield data is greater than that of the model (6.66 minutes and 4.86 minutes respectively). This difference is caused at least in part by the assumption in the explanatory model that frequency is equal over all routes.

Optimisation of the bus network model in terms of minimizing the average total walking and waiting time was shown to occur when the average walking time and the average waiting time are equal. This normative model was calibrated for Sheffield with route length R being derived, and two modifications of the model were investigated, namely the inclusion of a route factor of 1.29 and the addition of $0.075/V_w$ to the average walking time to reflect walking times to bus stops rather than to routes. The

incorporation of these factors and the selection of a walking speed of 3.5km/h gave a value of 374km for the route length. This is very similar to the route length measured over the study area, 391km, suggesting that the bus route length in Sheffield is approximately optimal. This is reinforced by the finding that the distributions of walking times for the Sheffield data and for the explanatory model are not significantly different. The fact that buses are not distributed equally over the Sheffield network means that the average waiting time is higher for the Sheffield data than for the model and thus the system is not optimal with regard to waiting time.

The addition of $0.075/V_w$ (to reflect the average time spent walking along the bus route to the nearest bus stop) to the average walking time for the Sheffield data gave a revised average walking time of 6.58 minutes at a walking speed of 3.5km/h. This is similar to the average waiting time for the Sheffield data of 6.66 minutes. The near equality of the average walking and waiting times suggests that overall the trade-off between route density and service frequency is approximately optimal in terms of minimizing access times to bus services in Sheffield.

CHAPTER 7

ACCESS TO BUS SERVICES IN SHEFFIELD : SPATIAL VARIATION

IN THE WALK AND WAIT ELEMENTS

1. Introduction

In the previous chapter access to bus services in Sheffield was investigated by measuring walking and waiting times. The walk and wait elements for the study area were compared with those obtained from a simple bus network model and conclusions concerning the overall optimality of the trade-off between route density and service frequency were drawn. The spatial variations in the walking and waiting time values over the Sheffield study area were inevitably concealed in this analysis.

The focus of this chapter is therefore on spatial variation in the walking and waiting time values measured within the Sheffield study area. After a review of the literature concerned with the spatial variation in access to public transport, the variables to be used in an attempt to explain the variation in the Sheffield study area are outlined. Basically the variables used can be divided into three groups : spatial (distance from a major road and distance from the city centre), historical (the corresponding walking and waiting times in 1962 and 1972) and socioeconomic (the proportions of the elderly, the young and

people in households without a car in the local population). The data collection methods are described in Section 4. Using these variables a regression model is constructed in Section 5. In Section 6 the socioeconomic variables are investigated in more detail in order to ascertain whether the provision of bus services within the study area is consistent with the declared policies of South Yorkshire County Council as discussed in Chapter 4. If these policies have not been consistently applied, then areas of the city which require better bus services in order to achieve the stated policy aims can be identified.

2. Literature review of spatial variation in access to public transport

A recent summary of market research and surveys undertaken into urban public transport services has shown that there is a fair degree of agreement as to what passengers and potential passengers regard as important constituents of quality of service, other than fares. After journey time the second most important attribute is ease of access to the system (Nash, 1982). Access to bus services consists of two components, the walking time and the waiting time, and as was shown in Chapter 6 the trade-off between route density and service frequency is critical if the public transport system is to operate effectively. Faulks (1981) is of the opinion that the suggested maximum walk of 400m

to a bus stop (Department of the Environment, 1973) "could prove over generous in application even in urban areas as it might produce a very dense network, in which case, either frequencies or load factors would fall below acceptable levels". Furth and Wilson (1981) have investigated frequencies on bus routes for a given fleet size and subsidy with the objective of maximising consumer surplus (the saving in waiting time that accrues to passengers who would have been prepared to use the system at lower frequencies). They recommend the expansion of midday services at the expense of peak period services. Similarly Jansson (1980) concludes that from the point of view of social cost minimization off-peak frequencies should be substantially higher. Daly and Last (1981) have used the TRANSEPT suite of programs developed by the Local Government Operational Research Unit to investigate various bus network and frequency patterns in Huddersfield in order to find the best available service given the current level of subsidy and the minimum subsidy required to maintain current levels of service. One of the six networks investigated possessed a maximum penetration of bus routes whilst another concentrated on the provision of maximum frequencies along major routes.

The topic of access to bus services including in particular the relationship between route density and service frequency has thus received some attention in the literature. However, the

focus of this chapter is more specifically on the spatial variation in access to bus services. Such variation is investigated in terms of its relationship to specific population groups, such as the elderly, the young and people without access to a car, and areas which are comparatively poorly served by public transport in relation to the proportion of residents reliant on public transport are identified. In the remainder of this section three pieces of research which employ similar approaches to that used to investigate the spatial variation in access to bus services in Sheffield are summarised.

Jarzab and Metalitz (1983) describe a procedure for determining the need for fixed-route bus services in Northeastern Illinois. The approach used is similar to that reported here except that, with the exception of employment levels, the socio-economic characteristics of the population are not incorporated into their model. The hypothesis on which their research is based is that "available bus services will be positively correlated to the population and employment density of served areas". An important feature of the research is that residuals from the regression equation describing the relationship between the bus service of each "quarter section", measured in terms of bus-miles/hour, and the resident and employee density of the sections are mapped to indicate areas of apparent over- or under-provision of bus services. Although in their final report

Jarzab and Metalitz (1979) state that "overall, suburban minority and low income population areas are at least as well served by suburban fixed-route bus transit as non-minority, non-low income suburban population areas" they anticipate that when data relating to income, ethnicity and bus ridership parameters become available and are incorporated into the model "these additional variables may prove significant as well" (1983).

Bird (1981) discusses the indices developed by several local authorities to highlight areas of need for public transport services and to distinguish which bus services are "providing access to facilities and meeting the needs of those in the population who do not have a car available to make necessary journeys". Only one of the indices, that of South Glamorgan County Council was developed for use in an urban area (Cardiff). As in the work reported here, the South Glamorgan index incorporates the proportions of the elderly, the young and non-car owning households. These proportions for each enumeration district are divided by the average proportions of each group in the city as a whole and the resulting ratios are weighted according to size. The weights for the three groups are then summed so that the higher the final score, the greater is the estimated need of the population for public transport. Public transport supply to each zone is measured by dividing the population of the zone by the number of peak hour buses passing

through. The population and public transport measures are then combined to pick out zones where public transport does not appear to be related to population characteristics. Bird then compares the results of analysing population and public transport data for three rural areas by each of the six indices and offers a cautionary conclusion concerning the use of such complex indices : "although the information included is considered relevant, its form and combination can produce arbitrary results".

Morphet (1979) has investigated access to bus services by social group in two London boroughs, Greenwich and Lambeth. The public transport input for the Greenwich research consisted of the mean walking times from the centroids of each of 400 enumeration districts to all bus stops within five minutes walk assuming a walking speed of 3.5mph and a route factor of 1.27 and waiting times based on half the average headway of buses as determined from the published timetable for peak, off-peak and weekend services. No account was taken of demand to reach particular destinations. Various socioeconomic variables were compared with data relating to access to bus services. Zero car owning households were shown to be relatively better served by bus services than the household population as a whole. Morphet then classified the enumeration districts into eight categories. Areas of high status, in which one would expect the least dependence on public transport, were found to be least well served in

terms of bus frequency. However, the next worst served category was that comprising public housing, including public housing with acute social stress and this "lack of bus services represents something of a failure of either land use or transport planning or both". The research conducted in Lambeth was concerned simply with the identification of areas located further than 400m from a bus stop (the Department of the Environment recommended maximum for urban areas, 1973). Seventeen bus deficiency areas were thus defined and Morphet concluded that transport services for the relatively under-privileged in Outer Areas seem to be considerably worse than in Inner Areas.

The research into the spatial variation in access to bus services in Sheffield reported in this chapter is similar in its overall approach to the work of Jarzab and Metalitz, Bird, and Morphet summarized above. However, more variables, in particular of a spatial and an historical nature, are introduced into the model to describe the variations in access to bus services in Sheffield and only those socioeconomic variables relevant to the policy aims of South Yorkshire County Council are investigated.

3. Variables

A model which seeks to describe spatial variation in access to bus services in Sheffield is developed in Section 5. This model contains three groups of variables which are of a spatial, historical and socioeconomic nature. These variables and the reasons for their selection are now described individually.

Two variables of a spatial nature, namely distance from a major road and distance from the city centre, are investigated. It can be hypothesized that the layout of the bus network will be to some extent influenced by the major road network, defined here as comprising 'A' and 'B' class roads. Thus a sampling point situated near an 'A' or 'B' road would be likely to have a lower walking time value than a sampling point situated further away from such roads. Thus a positive correlation between distance from major roads and walking time values is to be expected. Similarly it might be supposed that bus services will operate at higher frequencies along major roads than along other roads and thus a positive correlation between distance from major roads and waiting time values would occur. The other spatial variable to be included in the explanatory model is distance from the city centre. If the bus network approximates to a radial pattern based on the city centre, walking times to bus routes will increase as distance from the city centre increases. A positive correlation between waiting times and distance from the city centre will occur where services follow the same route from the centre and then diverge to serve different suburban areas or where some services terminate part way along routes.

It can be argued that the walking and waiting times for any sampling point at the present time will be closely related to the walking and waiting times for that point at an earlier period.

The slowness of change of public transport networks in general and the Sheffield bus network in particular has been discussed in Chapter 5. Thus the bus networks of 10 and 20 years ago are analysed in the same way as the present network in order to ascertain walking and waiting time values for all sampling points at these earlier periods. It is hypothesized that high positive correlations between the historic walking and waiting times and the present walking and waiting times will be found, confirming the importance of an historical approach in studies of this kind.

The final category of variables to be investigated concerns the socioeconomic characteristics of the population. These variables are used in the regression model described in Section 5 and they are investigated in more detail in Section 6 where the spatial variation in access to bus services is studied in relation to the declared policy aims of South Yorkshire County Council. A stated strategy of the South Yorkshire Structure Plan is to assist sections of the population in greatest need. "One such group is made up of those (including the poor, the old and the young) who have to travel by public transport because they do not have the regular use of a car... Policies aimed at improving public transport services are designed to benefit this group" (South Yorkshire Structure Plan Written Statement 1978, p.26). Variables relating to (i) the proportion of old people, (ii) the proportion of young people, and (iii) the proportion of people in

households without a car are investigated to see if this aim has been achieved in the Sheffield study area. The required data for these variables have been obtained from the Small Area Statistics of the Census. The other category of people in need mentioned above, namely the poor, is not directly used in the analysis because of the difficulty of obtaining an operational definition using Census data, for as Kemsley (1970) states, "in practice, there are no census variables which are highly correlated with income".

If the strategy of helping those who are reliant on public transport has been successfully implemented it would be expected that better public transport services (represented here by lower walking and waiting time values) would be found in areas with high proportions of the elderly, the young and people in households without cars. This would be indicated by high negative correlations between these three variables and the walking and waiting time values. Regression equations can then be calculated and residuals plotted. It is the positive residuals, i.e. those where access time to bus services is greater than expected, which indicate areas of Sheffield where bus services still require improvement in order to benefit these three groups of people in need.

It could be argued that households without a car will choose to live in areas already having a good public transport service. Thus a correlation between the lack of car ownership and access to bus services could be interpreted in terms of household location rather than in terms of public transport provision being related to need. However it has been shown that "households make significant trade offs between transportation services and other public service factors in evaluating potential residences, but that the role of both in determining where people choose to live is small compared with socioeconomic and demographic factors" (Weisbrod et al, 1980). Pickup (1984) has also studied the role of accessibility to public transport in relation to the residential mobility of council tenants and concludes that council tenants' moves of residence are more influenced by the quality of the local environment than by poor accessibility. Thus a correlation between car ownership levels and walking and waiting time values can be taken as evidence of public transport services being provided to benefit people who lack access to a car (rather than as evidence of people without a car choosing to live in areas having good accessibility to bus services).

A further group of dependent variables is introduced in Section 6 and consists of the improvements in the walking and waiting time values which have taken place since 1972. If the policies of South Yorkshire County Council regarding the

provision of bus services have been successfully implemented then positive correlations should be found between the proportions of the elderly, the young and those in households without a car and the improvements in walking and waiting time values which have occurred since 1972.

4. Data collection

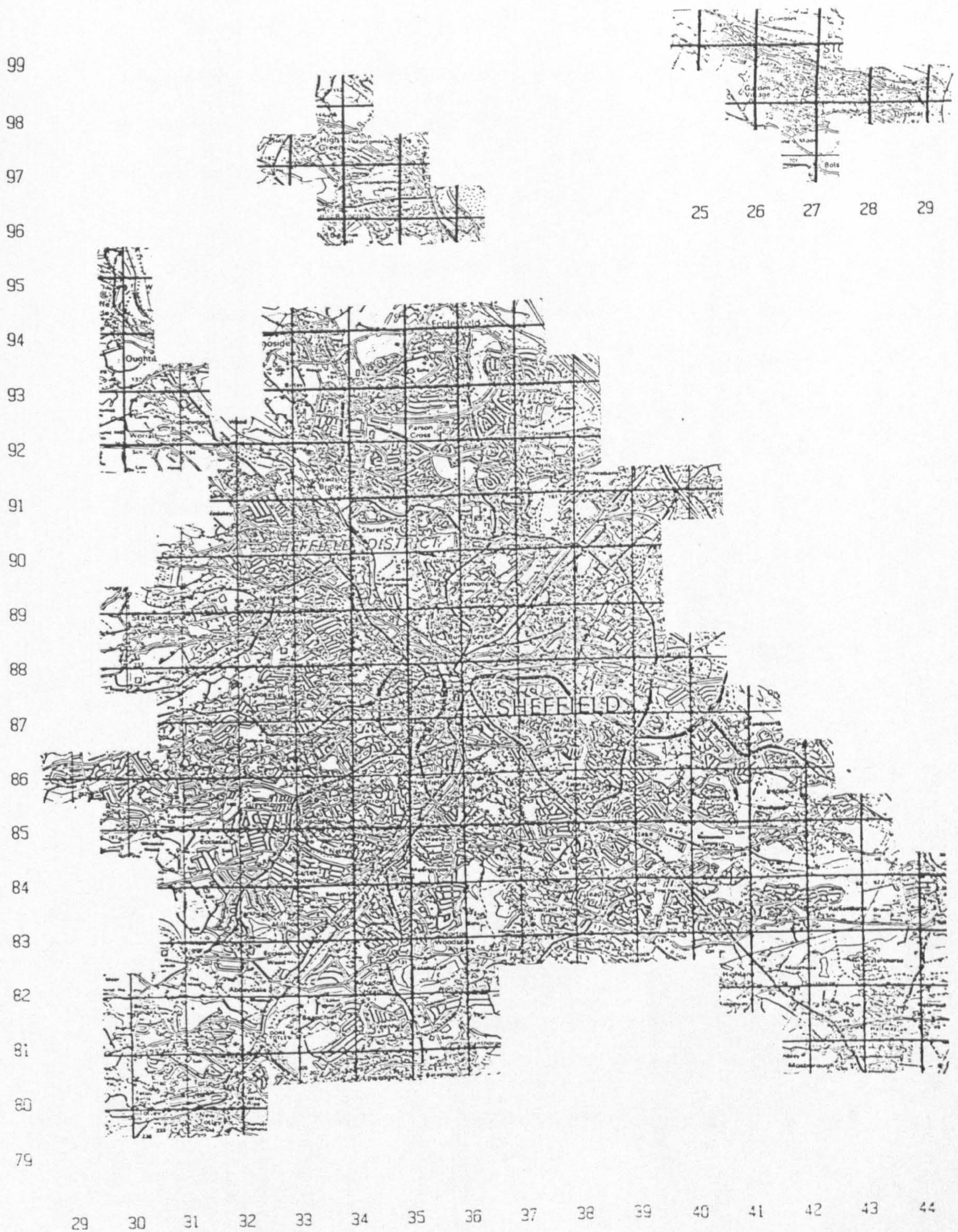
(i) Sampling framework

The sampling framework for the collection of walking and waiting time values is basically the same as that used in Chapter 6. A sampling point was defined as lying at the intersection of 1km National Grid lines if the kilometre square of which the intersection formed the midpoint contained housing in Sheffield. Two sampling points (3788 and 3179) used in Chapter 6 were eliminated from this study as they were situated in enumeration districts with zero returns in the 1981 Census. The sampling framework thus consisted of 168 points regularly spaced over the Sheffield study area.

Figure 7.1 is a map of the study area and sampling framework based on the OS 1:50000 map. It enables an impression to be gained of the locality of each sampling point.

Figure 7.1

The Sheffield study area
and sampling framework



(ii) Walking and waiting time values

The walking and waiting time values derived in Chapter 6 are used with some amendment in this study of the spatial variation in access to bus services. The method used to determine these values is described below.

For each sampling point the distance to the nearest bus route to Sheffield city centre was measured from the A-Z 4" to 1 mile map using a map measurer and moving from the point directly to the nearest road or footpath in the direction of the bus route and then along the road/footpath network to the bus route. Distances were measured to the nearest 1/8th mile (0.20km). The distance measurement was then converted to walking time by assuming a walking speed of 3.5km/h, this value having been derived from the study of the optimal relationship between average walking time and average waiting time reported in Chapter 6. Walking times relate to times taken to reach bus routes rather than bus stops because of the practical difficulties of measuring distances to specific bus stops.

The waiting time for each sampling point was defined as being half the average headway of buses along the nearest route to Sheffield city centre between 10.00 and 12.00 Monday to Friday. This was calculated from $120/2n$ minutes where n represents the number of buses during the 2 hour period. The

timetable which came into operation in June 1982 was used in conjunction with the April 1982 route map. Limited stop services were excluded (except in areas where they operate without restriction) as were services subject to minimum fares. For circular services based on the city centre, only buses in the direction most direct to the city centre were included. On the outer circular routes (Services 2 and 59) buses were included only when on a reasonably direct run into the city centre (i.e. from Crosspool for Service 2 and Ecclesall Road South for Service 59).

The walking and waiting time values were then summed for each point to provide a measure of the total access time to bus services.

For some sampling points the nearest route had a very infrequent service resulting in excessively long waiting times. Where the waiting time value for the nearest route exceeded 12 minutes, more distant bus routes were studied to find the route which provided the minimum walking plus waiting time combination assuming a walking speed of 4.8km/h (although the final walking time and the total time values were re-calculated with a walking speed of 3.5km/h). Thus for 38 points the walking time value does not reflect the time taken to reach the nearest bus route but to reach that route providing the lowest walking plus waiting time value.

The distributions of the walking, waiting and total time values are shown in Figures 7.2 to 7.4 and the actual values for each sampling point are presented in Appendices 7.1 to 7.3.

(iii) Variables

Each sampling point was assigned to the enumeration district in which it is situated and the 1981 Census Small Area Statistics (100%) were used to derive the socioeconomic variables. The timetables in operation between May and October 1962 and between January and May 1972 were used to obtain the historic walking and waiting time values.

The variables are summarized in Table 7.1.

Following the work of Poole and O'Farrell (1971) the characteristics of the variables were studied with respect to the assumptions involved in correlation and regression (Johnston, 1978, p.37-45). In particular histograms were plotted for each of the variables to check for normality and scattergrams were constructed for the dependent and independent variables to check for linear relationships. The distributions of most of the variables approximated to the normal distribution, although the distribution of the WALK variable was positively skewed. Because of the limited number of values taken by the WALK variable, and to a lesser extent by the WAIT variable, many of

Distribution of walking time values

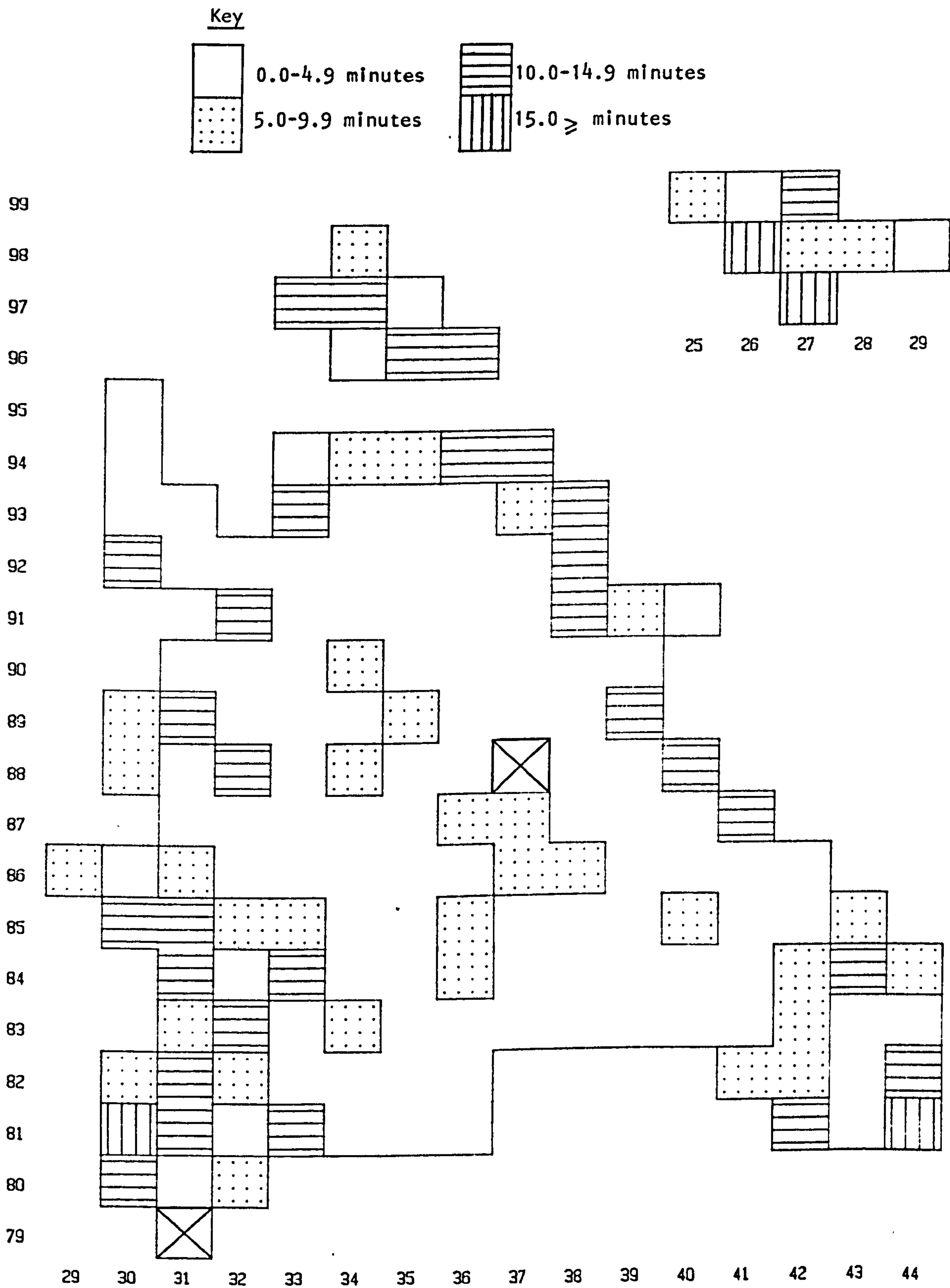
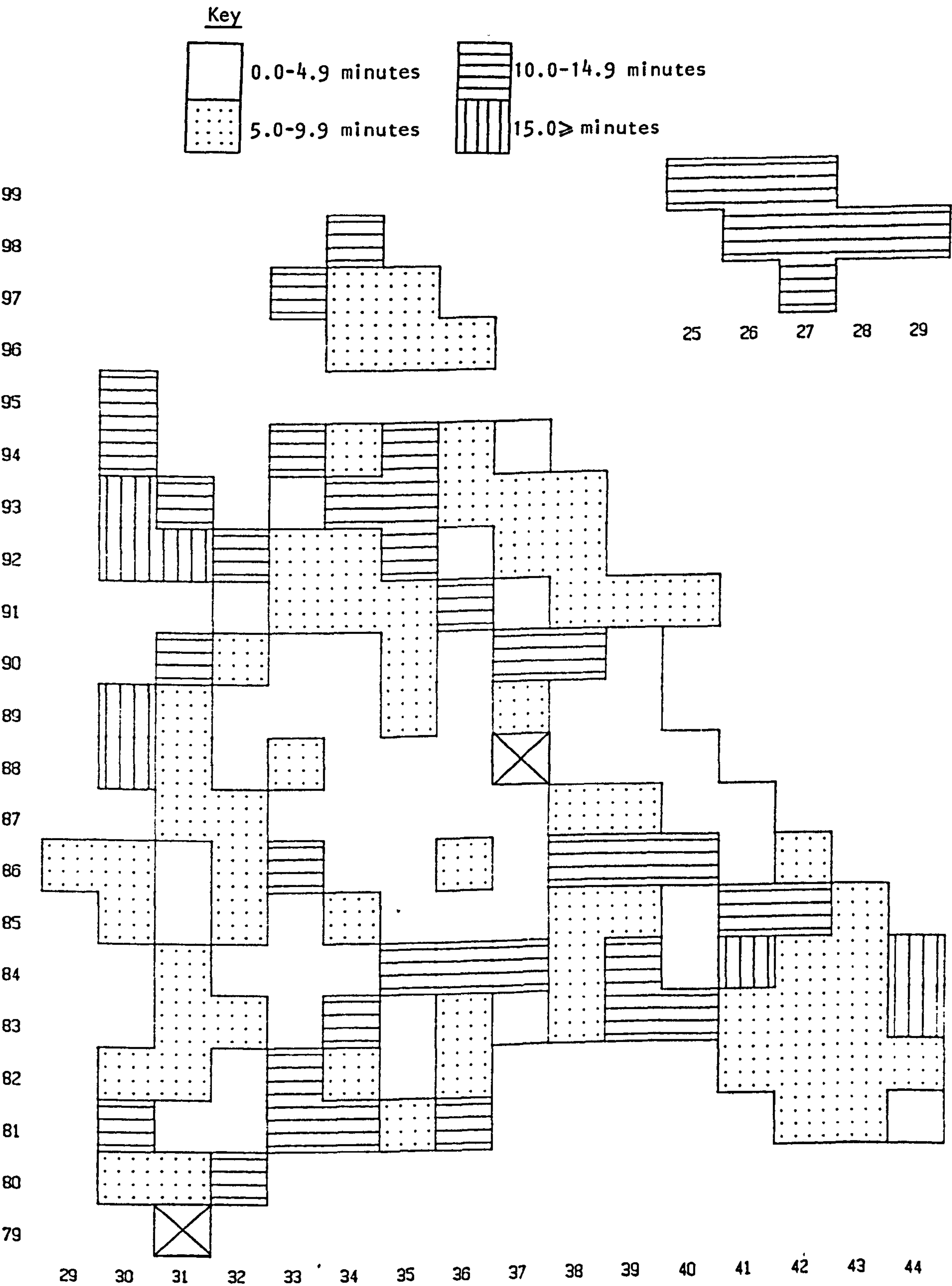


Figure 7.3

Distribution of waiting time values



Distribution of total time values

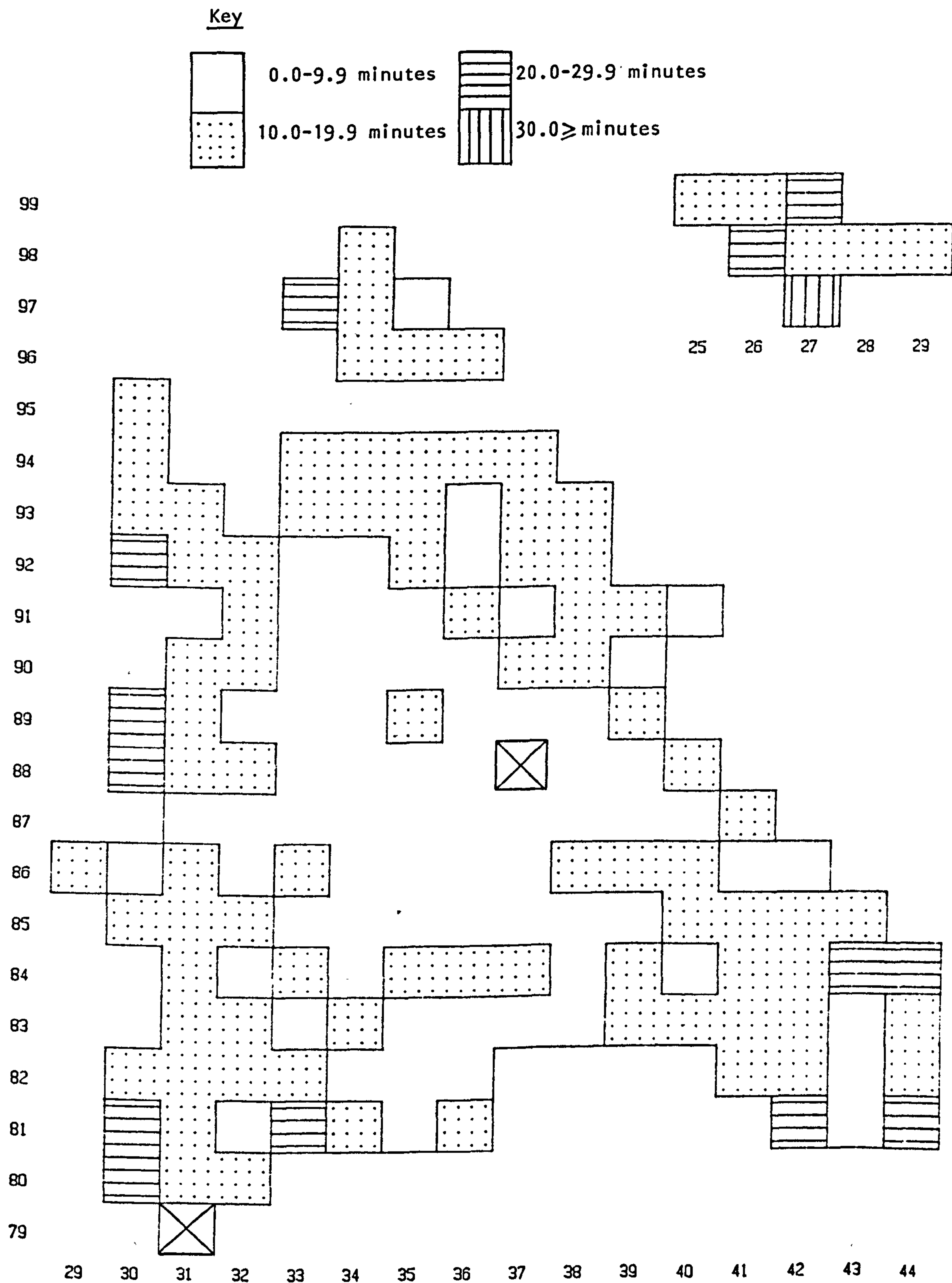


Table 7.1 Definition of variables

<u>Variable</u>	<u>Definition</u>
WALK	Walking time values at 1982, calculated as outlined in Section 4ii
WAIT	Waiting time values at 1982, calculated as outlined in Section 4ii
TOTAL	WALK + WAIT
ABROADS	Straight line distance from sampling point to nearest 'A' or 'B' road (measured from OS 1:50000 map)
CITYCENTRE	Straight line distance of sampling point from city centre, 355875, (calculated using the coordinates of the sampling point)
WALK62	Walking time value for each sampling point in 1962 (May - October 1962 timetable)
WAIT62	Waiting time value for each sampling point in 1962 (May - October 1962 timetable)
TOTAL62	WALK62 + WAIT62
WALK72	Walking time value for each sampling point in 1972 (January - May 1972 timetable)
WAIT72	Waiting time value for each sampling point in 1972 (January - May 1972 timetable)
TOTAL72	WALK72 + WAIT72
OLD	Number of residents aged 65 and over as a percentage of all residents in the enumeration district (Census, Table 2) (Values shown in Appendix 3.2)
YOUNG	Number of residents aged 15 and under as a percentage of all residents in the enumeration district (Census, Table 2) (Values shown in Appendix 3.1)
NOCAR	People in households without a car as a percentage of all people in the enumeration district (Census, Table 12) (Values shown in Appendix 3.3)
IMPWALK	Improvement in the walking time values between 1972 and 1982 : WALK72 - WALK
IMPWAIT	Improvement in the waiting time values between 1972 and 1982 : WAIT72 - WAIT
IMPTOTAL	Improvement in the total access time values between 1972 and 1982 : TOTAL72 - TOTAL

the scattergrams displayed a banded pattern. This is reflected in the low correlation coefficients obtained during the regression procedure as outlined in the following sections. For most of the independent variables the value of each observation was largely independent of all other values (although some areal patterns were discernible particularly within the socioeconomic variables) and thus the assumption of autocorrelation was generally fulfilled.

5. A regression model of spatial variation in access to bus services

Table 7.2 shows the regression equations and correlation coefficients between the independent variables outlined in Section 4iii and the walking, waiting and total time values. It will be noted that with the exception of the historical variables, the WALK and WAIT regression equations for each variable can be added to give the regression equation for TOTAL. This occurs because of the very low correlation ($r=0.07$) between the walking time values and the waiting time values.

The correlation coefficients between WALK and ABROADS and CITYCENTRE of 0.46 and 0.42 respectively indicate that both the major road network and distance from the city centre influence the walking component of access to bus services to some extent.

Table 7.2 Regression analysis

<u>Equation</u>	<u>Correlation coefficient</u>	<u>F ratio</u>
WALK = 2.92 + 6.20 ABROADS	0.46	43.9
WAIT = 5.99 + 1.84 ABROADS	0.18	5.61
TOTAL = 8.90 + 8.04 ABROADS	0.46	43.5
WALK = 1.40 + 0.68 CITYCENTRE	0.42	36.2
WAIT = 3.24 + 0.61 CITYCENTRE	0.50	55.8
TOTAL = 4.63 + 1.29 CITYCENTRE	0.62	100.8
WALK = 0.88 + 0.74 WALK62	0.76	228.1
WAIT = 3.93 + 0.34 WAIT62	0.54	68.3
TOTAL = 3.15 + 0.63 TOTAL62	0.81	307.6
WALK = 0.43 + 0.89 WALK72	0.89	644.9
WAIT = 3.33 + 0.42 WAIT72	0.67	134.6
TOTAL = 3.11 + 0.66 TOTAL72	0.84	389.6
WALK = 5.48 - 0.012 OLD	-0.02	0.06
WAIT = 6.69 - 0.0005 OLD	-0.001	0.0002
TOTAL = 12.12 - 0.013 OLD	-0.02	0.04
WALK = 3.12 + 0.100 YOUNG	0.12	2.47
WAIT = 6.63 + 0.002 YOUNG	0.004	0.003
TOTAL = 9.75 + 0.103 YOUNG	0.10	1.52
WALK = 7.74 - 0.069 NOCAR	-0.29	15.0
WAIT = 7.77 - 0.031 NOCAR	-0.17	5.0
TOTAL = 15.45 - 0.099 NOCAR	-0.32	18.9

The regression equation for WALK and ABROADS suggests that for every additional kilometre from an 'A' or 'B' road, the average walking time to a bus route tends to increase by approximately 6 minutes. The regression equation for WALK and CITYCENTRE indicates that for each kilometre moved away from the city centre an extra 0.7 minutes is expended on walking to the bus route. Such a relationship between walking times and distance from the city centre suggests that the bus network can be represented by a radial network. Using the variables for the Sheffield study area given in Chapter 6 (Section 3i) the radial model can be quantified for the Sheffield study area. This is shown in Figure 7.5 and it is found that on average an extra distance of 0.03km is walked to reach a bus route for each kilometre moved out from the city centre. At a walking speed of 3.5km/h this additional distance will take 0.51 minutes, 0.17 minutes less than that suggested by the regression equation. This difference is not sufficiently large to invalidate the value of the radial model. It does however suggest that some bus routes terminate before reaching the boundary of the study area, a view supported by an inspection of the Sheffield route map.

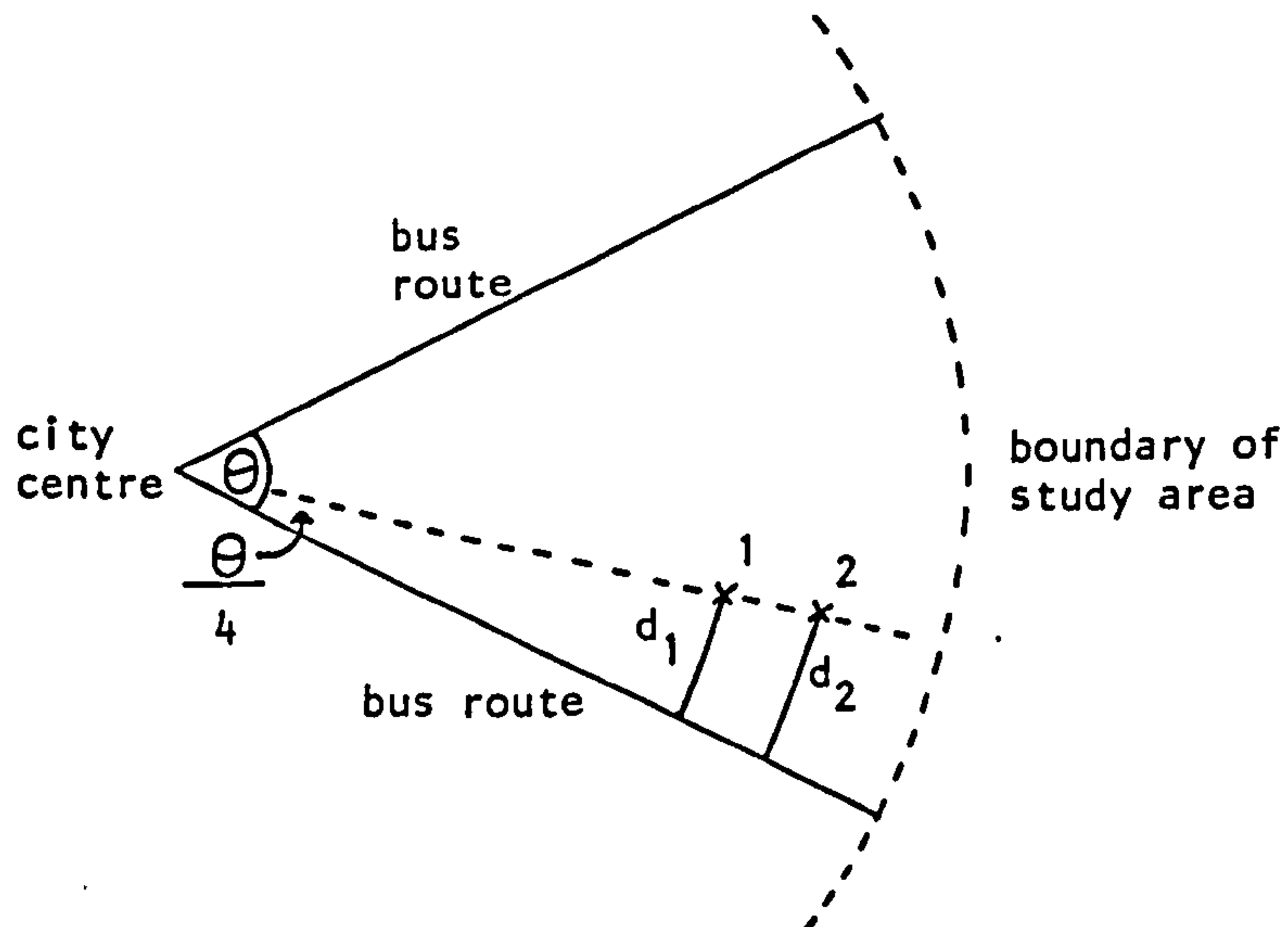
The correlation coefficient between WAIT and ABROADS is low (0.18) suggesting that although the bus route network is to some extent determined by the major road network ($r=0.46$ for WALK and ABROADS), the frequency of bus services is not influenced by the

To find : the additional average distance walked for each additional kilometre from the city centre.

For the study area:

$$A = \text{area} = 170 \text{ km}^2$$

$$R = \text{route length} = 391 \text{ km}$$



Consider points 1 and 2 with average walking distances for their distance from the city centre such that the distance between them is 1 km: point 1 is x km from the city centre, point 2 is $(x + 1)$ km from the city centre.

To find : difference in walking distance from points 1 and 2

$$= d_2 - d_1$$

$$= \frac{2\pi(x + 1)\theta}{4.360} - \frac{2\pi x\theta}{4.360}$$

$$= \frac{\theta\pi}{720} \quad \text{but } \theta = \frac{360}{\text{no. of bus routes}} = \frac{360}{R\sqrt{\pi}} = 6.77$$

$$= 0.0296 \text{ km.}$$

\therefore the additional average distance walked for each additional kilometre from the city centre is 0.0296 km.

status of the road. The correlation coefficient between WAIT and CITYCENTRE (0.50) indicates that waiting time values are quite strongly related to distance from the city centre. The regression equation indicates that waiting time tends to increase by 0.6 minutes for every kilometre moved away from the city centre. This relationship could arise in two ways; firstly bus routes could merge towards the city centre leading to increased frequency of services nearer the centre, and secondly, some services could terminate part way along routes. From a study of the Sheffield bus timetable and route map it would appear that whilst the second type occurs along some routes, this relationship between waiting times and distance from the city centre occurs primarily through route mergers.

The historical variables produce high positive correlation coefficients, suggesting that the present bus network is closely related to the network at earlier periods. The walking time variables are more highly correlated for both time periods than the waiting time variables, indicating that more change has occurred in the frequency of bus services than in the actual layout of the bus network. The changes which have occurred between 1972 and 1982 are investigated in more detail in Section 6 where particular attention is given to the improvements in access to bus services in relation to the distribution of the elderly, the young and households without cars.

Of the three socioeconomic variables investigated, NOCAR is the most strongly correlated with access to bus services, although the correlation is rather weak ($r=-0.32$ for TOTAL and NOCAR). The regression equation for TOTAL and NOCAR indicates that for every 10% increase in people in households without a car in the local population, total access time to bus services tends to decrease by one minute. The relationships between the OLD and YOUNG variables and access to bus services are very weak.

Beale's Algorithm (Beale et al, 1968) was used to combine the variables in order of importance in reducing the relative residual. It should be noted that the 1962 walking, waiting and total time variables have not been included because they are not independent of the 1972 variables ($r=0.85$ for WALK62 and WALK72, 0.89 for WAIT62 and WAIT72 and 0.95 for TOTAL62 and TOTAL72). The results are presented in Table 7.3.

The importance of the historical variable in explaining the pattern of each of the three dependent variables is clearly shown. The relative residual between WALK and WALK72 is 0.205, the incorporation of the ABROADS variable reduces this to 0.201 but the inclusion of the other four variables reduces the relative residual by only 0.005. If the historical variable is taken out of the explanatory model, then the relative residual between WALK and the other variables, ABROADS, CITCYCENTRE,

Table 7.3 Relative residuals

<u>Dependent variable</u>	<u>Independent variables</u>	<u>Relative residual</u>
WALK	WALK72	0.205
WALK	WALK72, ABROADS	0.201
WALK	WALK72, ABROADS, CITYCENTRE	0.197
WALK	WALK72, ABROADS, CITYCENTRE, NOCAR	0.196
WALK	WALK72, ABROADS, CITYCENTRE, NOCAR, OLD	0.196
WALK	WALK72, ABROADS, CITYCENTRE, NOCAR, OLD, YOUNG	0.196
<u>Regression equation</u>		<u>t value</u>
WALK = 0.513		
+ 0.834 WALK72		(19.704)
+ 0.864 ABROADS		(1.610)
+ 0.093 CITYCENTRE		(1.458)
- 0.009 OLD		(-0.292)
- 0.011 YOUNG		(-0.270)
- 0.007 NOCAR		(-0.740)

Table 7.3 (continued)

<u>Dependent variable</u>	<u>Independent variables</u>	<u>Relative residual</u>
WAIT	WAIT72	0.552
WAIT	WAIT72, CITYCENTRE	0.529
WAIT	WAIT72, CITYCENTRE, YOUNG	0.526
WAIT	WAIT72, CITYCENTRE, YOUNG, OLD	0.523
WAIT	WAIT72, CITYCENTRE, YOUNG, OLD, ABROADS	0.520
WAIT	WAIT72, CITYCENTRE, YOUNG, OLD, ABROADS, NOCAR	0.520
<u>Regression equation</u>		<u>t value</u>
WAIT = 4.456		
+ 0.357 WAIT72		(8.241)
+ 0.529 ABROADS		(0.865)
+ 0.214 CITYCENTRE		(2.447)
- 0.032 OLD		(-0.867)
- 0.067 YOUNG		(-1.377)
- 0.003 NOCAR		(-0.291)

Table 7.3 (continued)

<u>Dependent variable</u>	<u>Independent variables</u>	<u>Relative residual</u>
TOTAL	TOTAL72	0.299
TOTAL	TOTAL72, ABROADS	0.279
TOTAL	TOTAL72, ABROADS, CITYCENTRE	0.270
TOTAL	TOTAL72, ABROADS, CITYCENTRE, NOCAR	0.266
TOTAL	TOTAL72, ABROADS, CITYCENTRE, NOCAR, YOUNG	0.266
TOTAL	TOTAL72, ABROADS, CITYCENTRE, NOCAR, YOUNG, OLD	0.265
<u>Regression equation</u>		t value
TOTAL = 4.444		
+ 0.552 TOTAL72		(12.229)
+ 2.597 ABROADS		(3.278)
+ 0.226 CITYCENTRE		(1.966)
- 0.026 OLD		(-0.564)
- 0.049 YOUNG		(-0.824)
- 0.019 NOCAR		(-1.354)

NOCAR, OLD and YOUNG, is 0.669. The pattern displayed by the Beale's Algorithm analysis for TOTAL is similar to that for WALK. TOTAL72 is the most important independent variable, leaving a relative residual of 0.299. The incorporation of the ABROADS variable reduces this to 0.279, whilst the inclusion of the other variables (CITYCENTRE, NOCAR, YOUNG and OLD in order of importance) reduces the relative residual to 0.265. The dominance of the historical variable is again illustrated by the fact that the relative residual between TOTAL and the other five independent variables is 0.511.

The regression model does not adequately account for the variation in the WAIT variable. Whilst the historical variable is again the most important it leaves a high relative residual of 0.552. The combination of WAIT72 and CITYCENTRE reduces the relative residual to 0.529 and the incorporation of the other four variables reduces the relative residual by only 0.009 to 0.520.

The regression equations incorporating all the independent variables are given in Table 7.3.

For all three variables relating to present day access to bus services (WALK, WAIT and TOTAL), the historical variable is dominant in describing the pattern of spatial variation. This

dominance reinforces the argument made elsewhere in this thesis that the bus network of Sheffield is a slowly changing system incorporating elements of historical inertia. Nevertheless some of the other variables investigated do play a significant role in describing the pattern of spatial variation in access to bus services over and above the 1972 variables.

It should be noted that the fairly high relative residuals between WALK, WAIT and TOTAL and the spatial and socioeconomic variables occur to a certain extent because of the indivisible nature of bus service provision which leads to a very irregular surface of accessibility. An increase in the density of the sampling framework would not necessarily have produced higher correlation coefficients and lower relative residuals because of this irregular surface. The technique of area smoothing may have improved the description of the pattern of spatial variation in access to bus services but was not attempted because of time constraints.

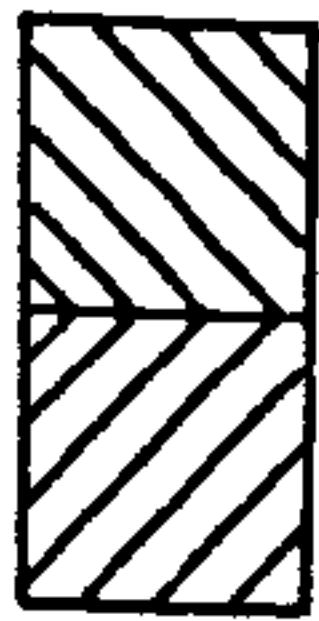
Because of the poor level of explanation of the waiting time variable achieved by the model, large positive and negative residuals from the regression equation between WAIT and the six independent variables were investigated. These residuals are shown on a map of the study area in Figure 7.6. Several of the positive residuals are located on the north western periphery of

Figure 7.6

Residuals from the regression equation

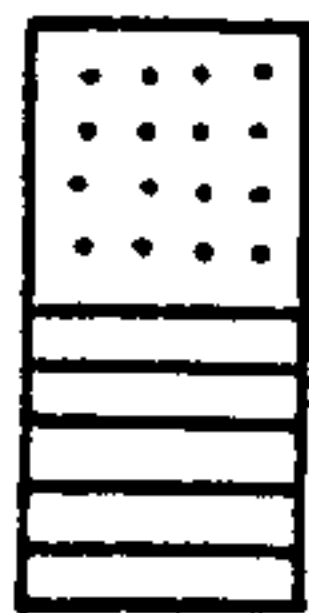
$$\begin{aligned} \text{WAIT} = & 4.456 + 0.357 \text{ WAIT72} + 0.529 \text{ ABROADS} \\ & + 0.214 \text{ CITYCENTRE} - 0.032 \text{ OLD} \\ & - 0.067 \text{ YOUNG} - 0.003 \text{ NOCAR} \end{aligned}$$

Key (Sy = 2.54)



+2-3 Sy

+1-2 Sy



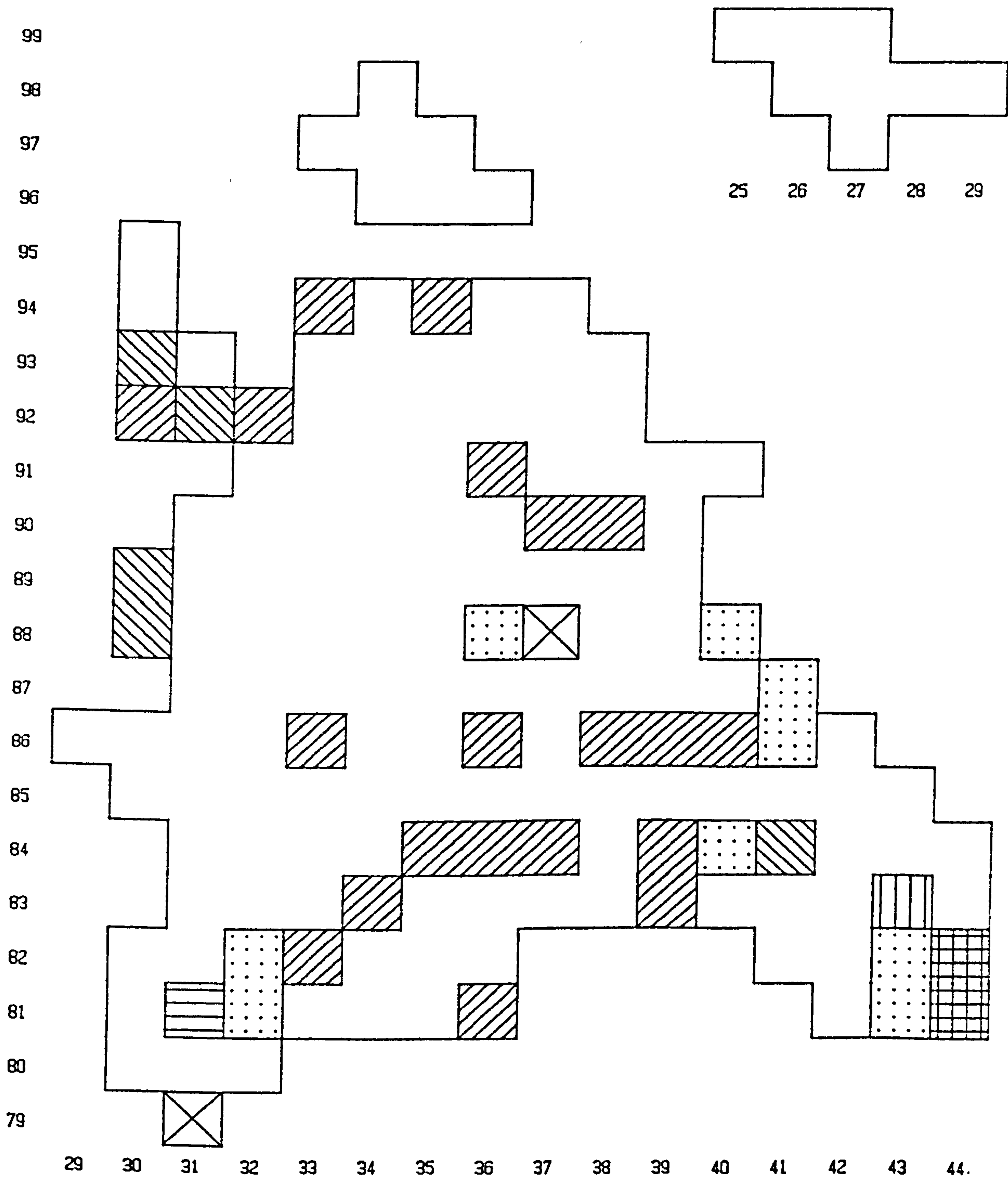
-1-2 Sy

-2-3 Sy



-3-4 Sy

-4-5 Sy



the study area. Much of this area is of a semi-rural nature and it is possible that the introduction of a variable relating to population density would improve the level of explanation achieved by the model. The occurrence of a cluster of negative residuals in the SE corner of the study area should be noted. This is because the Mosborough area where extensive residential development has taken place since 1972 has seen marked improvements in its bus services and therefore reductions in its waiting time values. Thus the WAIT72 variable in particular does not adequately account for the present day bus services in this area. Access to bus services in the Mosborough area is investigated in detail in Chapter 8.

The regression equations were re-worked omitting the data from the 14 sampling points situated in the Mosborough ward. The regression equations for single variables are similar to those for the whole study area as given in Table 7.2. The magnitude of the correlation coefficients is slightly improved for many of the variables, the most notable improvement occurring for the 1972 variables ($r=0.97$ for WALK and WALK72, 0.88 for WAIT and WAIT72 and 0.97 for TOTAL and TOTAL72). The relative residuals are much smaller when Mosborough is omitted from the study area, being 0.058 for WALK and WALK72, ABROADS, OLD, CITYCENTRE, NOCAR, YOUNG, 0.216 FOR WAIT and WAIT72, YOUNG, CITYCENTRE, NOCAR, ABROADS, OLD and 0.053 for TOTAL and TOTAL72, ABROADS,

CITYCENTRE, YOUNG, NOCAR, OLD. Thus the regression model adequately describes the spatial variation in access to bus services in the Sheffield study area with the exception of Mosborough.

6. Spatial variation in access to bus services in relation to declared policy

As stated in Section 3 the policy of South Yorkshire County Council is to provide bus services to benefit groups of people in need, such as the elderly, the young and people without access to cars. Thus, if provision is consistent with declared policy areas with a high proportion of any of these groups would be expected to have better bus services, in terms of relatively small walking and waiting times, than other areas.

The regression equations and correlation coefficients between the socioeconomic variables, OLD, YOUNG and NOCAR, and the walking, waiting and total time values are given in Table 7.2. The relationships are very weak, indicating that bus service provision does not reflect policy aims. This failure to match provision to need has been acknowledged in the local press : "Many routes have been there since the 1930s and changes are due because people are not living in the same places now"

(Morning Telegraph (Sheffield) 4th February 1984) and "There must be positive discrimination with money spent on service development with a social priority" (Star (Sheffield) 19th May 1982.).

The changes in the walking and waiting time values between 1962, 1972 and 1982 provide an indication of the level of improvements in access to bus services which have taken place. If South Yorkshire County Council's policies have been successfully implemented then improvements in walking and waiting time values would be expected to have occurred since 1972 especially in areas with high proportions of the elderly, the young and people in households without cars. The average walking, waiting and total time values for the three years are given in Table 7.4. The importance of the 1972 values in explaining the 1982 values has been demonstrated in Section 5. It is interesting to note that since 1972 more improvement has occurred in waiting time values (mean 1972 7.94, mean 1982 6.68) than in the walking time values (mean 1972 5.38, mean 1982 5.24), indicating that improvements to bus services have largely taken the form of improved frequency on existing routes. Between 1962 and 1972 overall access to bus services improved by only 0.57 minutes, compared with 1.40 minutes between 1972 and 1982, indicating that the rate of improvement in access to bus services has increased since the formation of South Yorkshire County Council.

Table 7.4 Walking, waiting and total time values,
1962, 1972 and 1982

	<u>Mean (minutes)</u>		
	1962	1972	1982
WALK	5.92	5.38	5.24
WAIT	7.97	7.94	6.68
TOTAL	13.89	13.32	11.92

<u>Correlation coefficients</u>			
WALK	v	WALK62	0.76
WAIT	v	WAIT62	0.54
TOTAL	v	TOTAL62	0.81
WALK	v	WALK72	0.89
WAIT	v	WAIT72	0.67
TOTAL	v	TOTAL72	0.84
WALK72	v	WALK62	0.85
WAIT72	v	WAIT62	0.89
TOTAL72	v	TOTAL62	0.95

The 1982 walking, waiting and total time values were subtracted from the 1972 values to provide a measure of the improvement in access to bus services at each sampling point. Overall the improvement in access to bus services between 1972 and 1982 was 0.14 minutes for WALK, 1.26 minutes for WAIT and 1.40 minutes for TOTAL. However, these average figures mask much variation, as shown in Table 7.5.

Table 7.5 Improvements in access to bus services 1972-1982

Variable	Mean	Standard deviation	Minimum value	Maximum value
IMPWALK	0.14	3.30	-10.4	17.2
IMPWAIT	1.26	4.68	- 7.7	25.7
IMPTOTAL	1.40	4.61	- 4.5	27.2

The correlation coefficients between the improvement variables and the three socioeconomic variables are shown in Table 7.6.

Table 7.6 The relationship between improvements in access to bus services 1972-1982 and the socioeconomic variables

	<u>Correlation coefficients</u>		
	OLD	YOUNG	NOCAR
IMPWALK	0.035	0.018	0.046
IMPWAIT	0.027	0.079	-0.045
IMPTOTAL	0.045	0.087	-0.021

These very low correlation coefficients indicate that the improvements in access to bus services which have taken place in Sheffield in recent years have not particularly benefitted those

groups of the population dependent on public transport. The correlation coefficient between IMPTOTAL and CITYCENTRE is 0.31, indicating that much of the improvement in access to bus services has taken place at greater distances from the city centre. This is also shown in Figure 7.7 which indicates those sampling points which have experienced a significant improvement in access to bus services between 1972 and 1982. The most concentrated area of improvement is the Mosborough district in the SE of the Sheffield study area. The relationship between the residential growth of this area and the introduction of new bus services is studied in Chapter 8.

The 1982 data collected for the Sheffield study area can be used to indicate areas where bus services should be improved, either through the introduction of additional routes or through an increase in frequency along existing routes, in order to benefit groups of the population in need and thereby achieving declared policy aims. Residuals from the regression equations between walking times and waiting times and the three socio-economic variables have been studied. In particular positive residuals indicate points having higher walking or waiting times than would be expected from the proportion of the old, the young or people in households without a car in the enumeration districts in which these points are situated. A point lying over plus 1 standard error from the regression line is defined as having a poor service and as an example Figure 7.8 shows such points having large walking times in relation to the proportion of elderly people in the local population.

Figure 7.7

Changes in access to bus services 1972-1982
(TOTAL72 - TOTAL82)

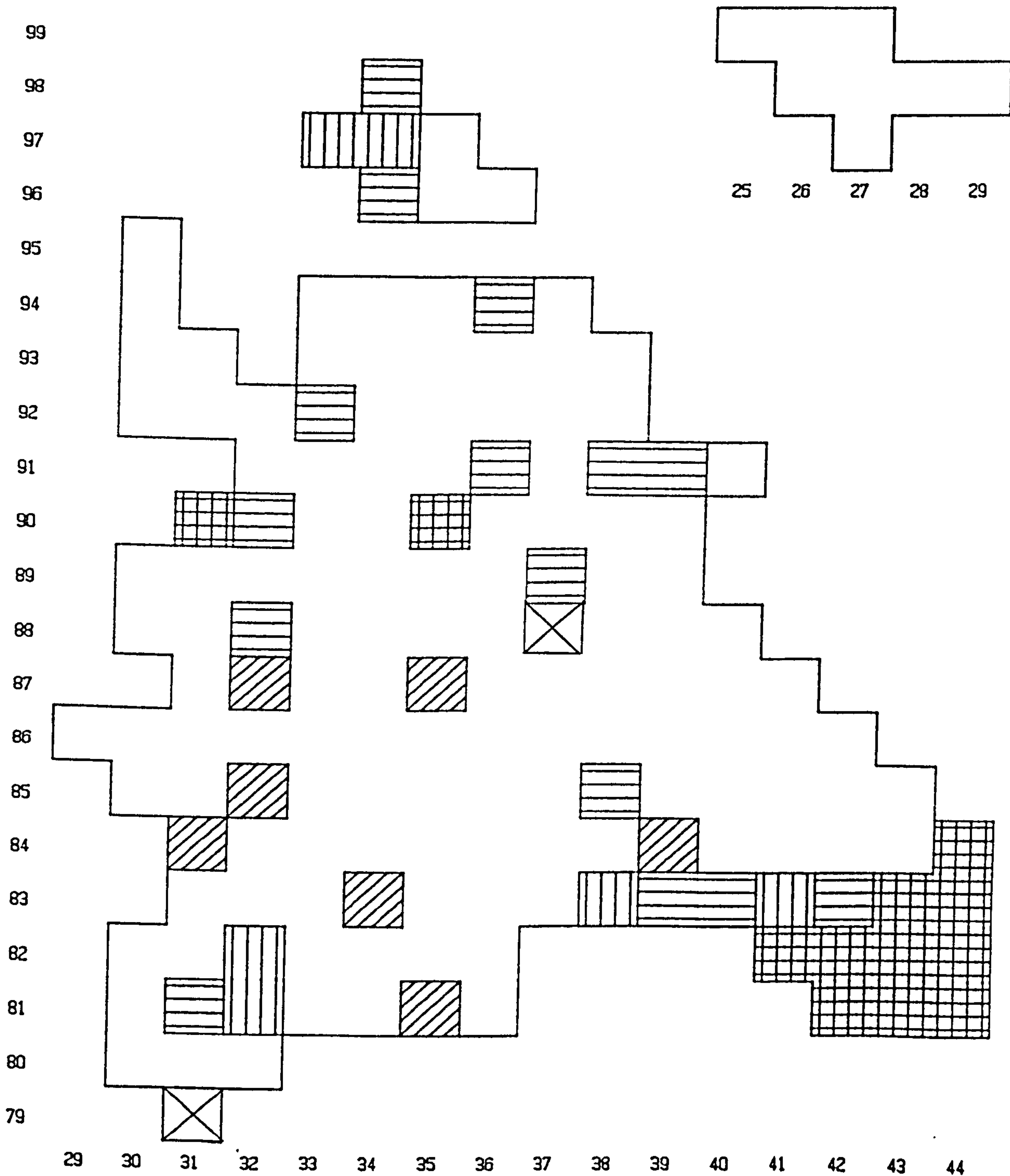
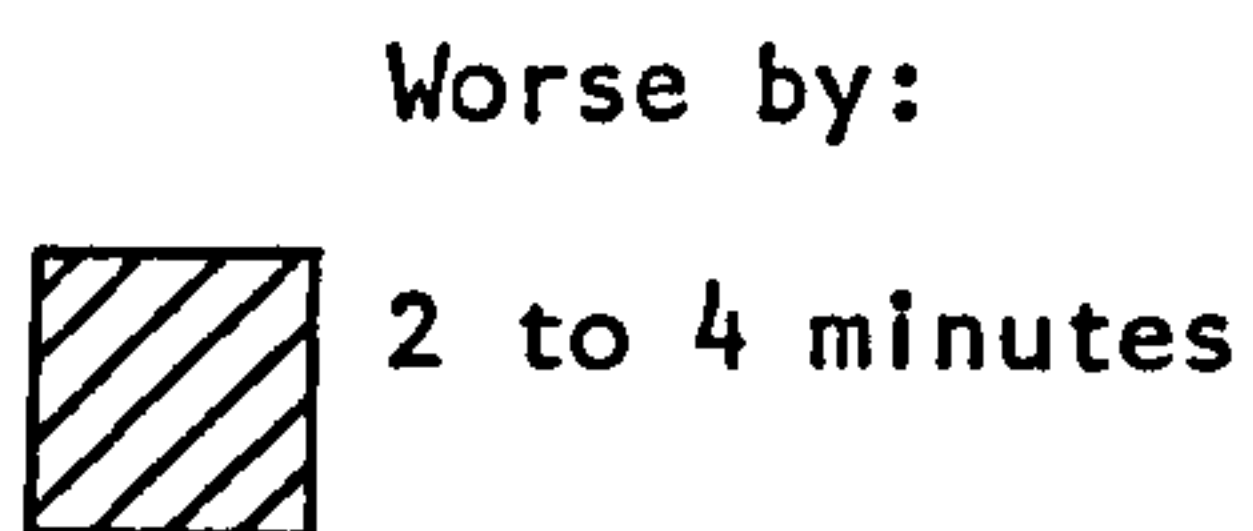
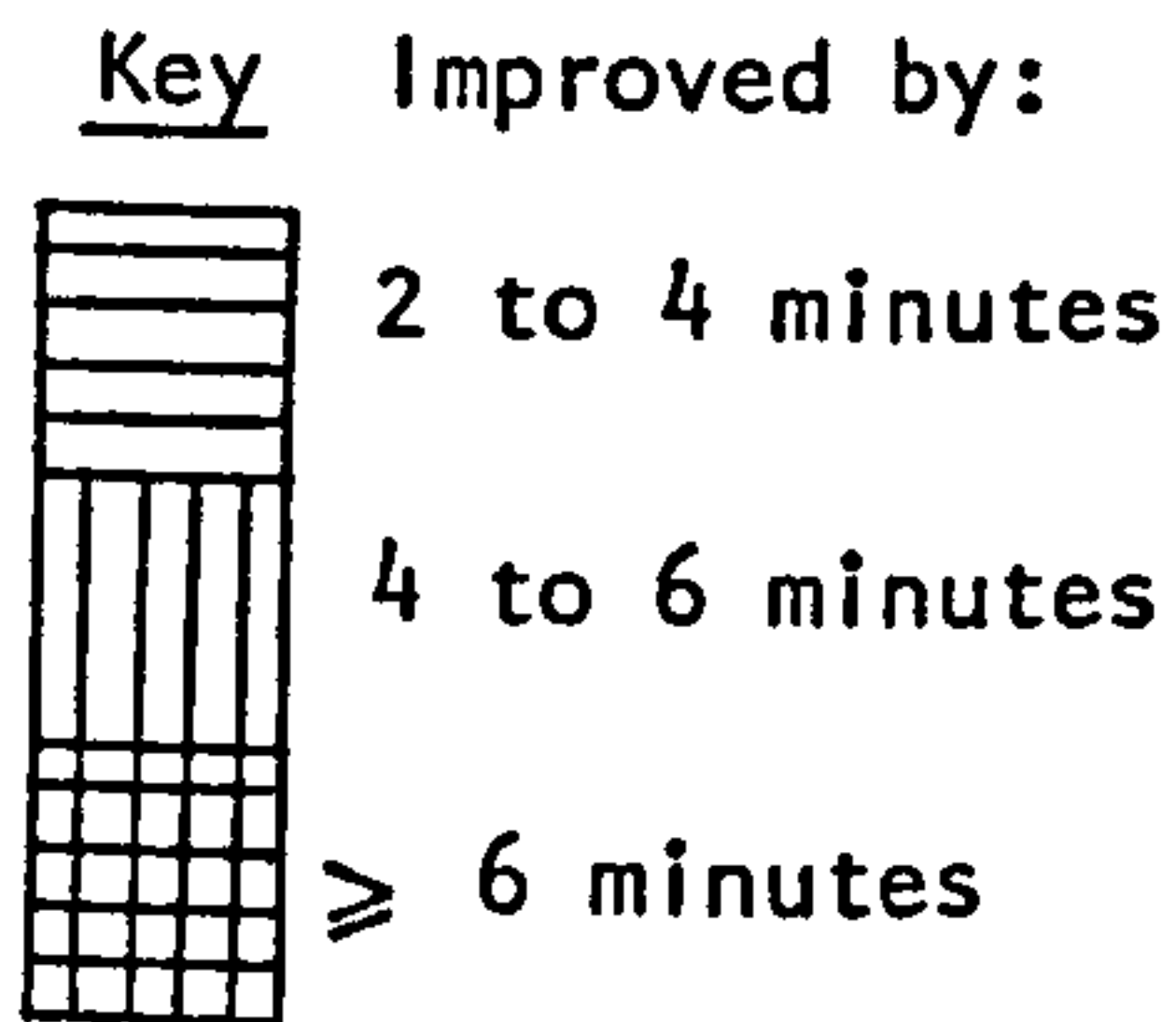


Figure 7.8

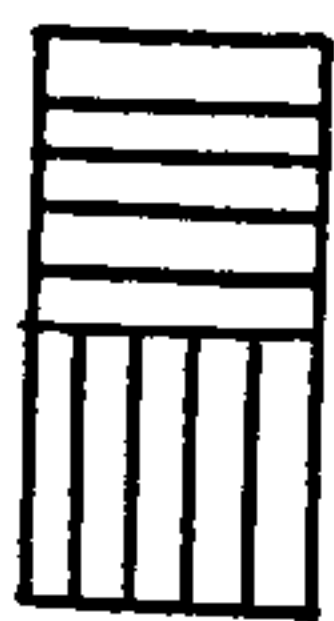
The relationship between WALK and OLD

$$WALK = 5.427 - 0.012 \text{ OLD}$$

$$r = -0.020$$

$$Sy = 4.67$$

Key



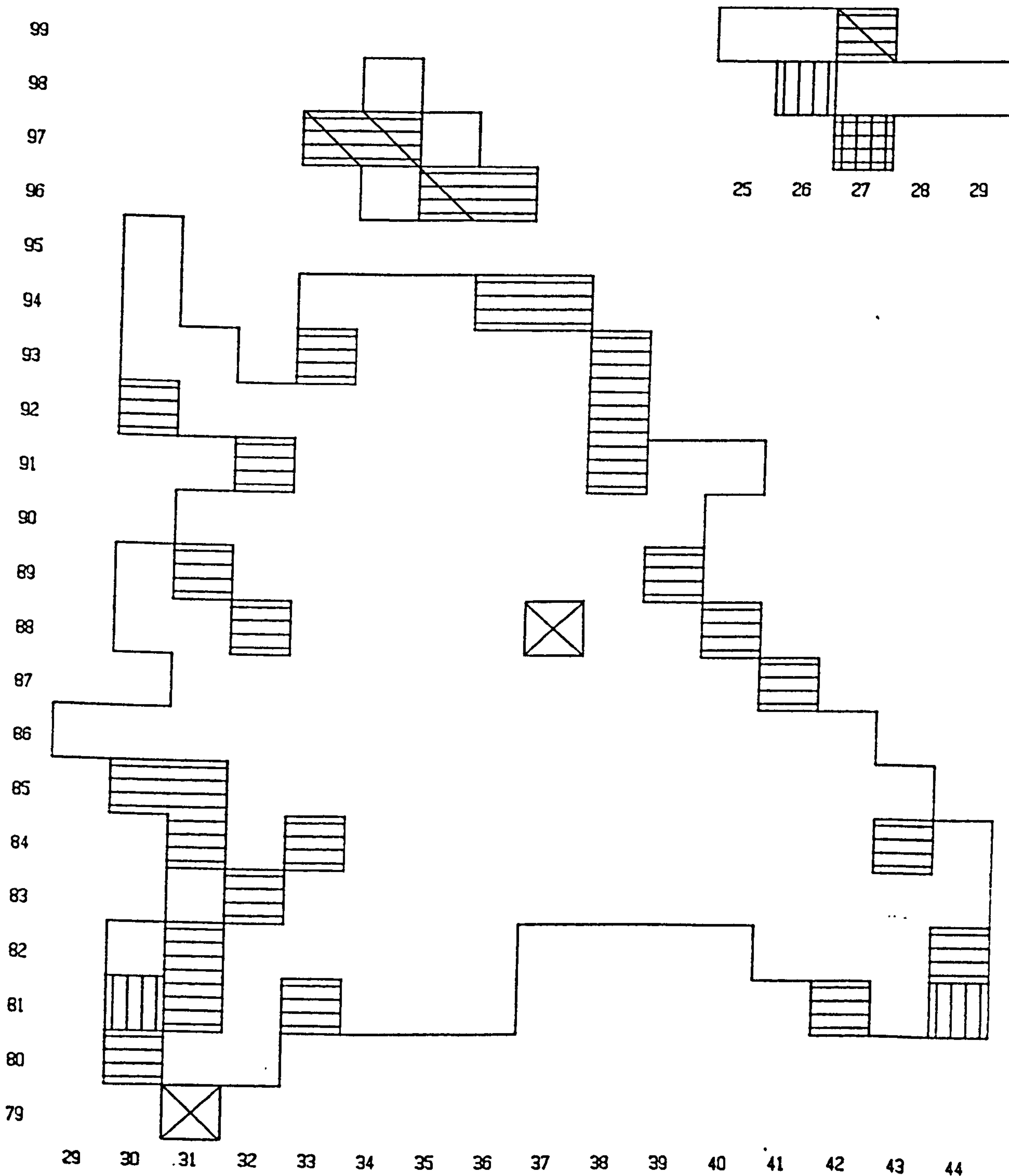
+1-2 Sy (4.67-9.34 minutes)

+2-3 Sy (9.34-14.02 minutes)



> 3 Sy (> 14.02 minutes)

point lies < +1Sy from WALK/
CITYCENTRE regression line



Many of the points experiencing poor access to bus services in relation to their socioeconomic characteristics are peripheral, which suggests that bus routes should be extended and frequency of services improved towards the boundary of the study area. In relation to the proportion of the young and elderly in the population, the south western sector of the study area has large walking times to bus routes. Thus the density of bus routes in this sector must be increased to benefit those people, particularly the elderly and the young, without access to a car, even though car ownership levels are higher than elsewhere in the city (for the wards of Dore and Ecclesall NOCAR = 20% v. city average of 43%). Also worth noting are two points, 3687 and 3787, located very near to the city centre which have poor access to bus services in relation to their very low car ownership rates (82% and 77% of people live in households without a car). The positive residuals between WAIT and NOCAR, shown in Figure 7.9, indicate three areas of the city where frequency of bus services must be increased in order to provide services consistent with declared policy. These are (1) the north western edge of the study area including Stocksbridge, (2) to the north of the city centre (Parson Cross, Longley and Grimesthorpe districts) and (3) a large area in the south east of the study area.

Figure 7.9

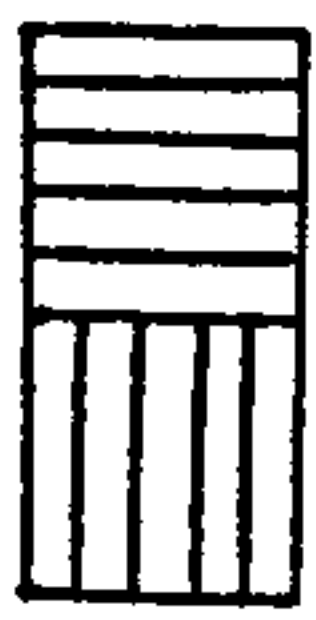
The relationship between WAIT and NOCAR

$$\text{WAIT} = 7.772 - 0.031 \text{ NOCAR}$$

$$r = -0.171$$

$$S_y = 3.47$$

Key

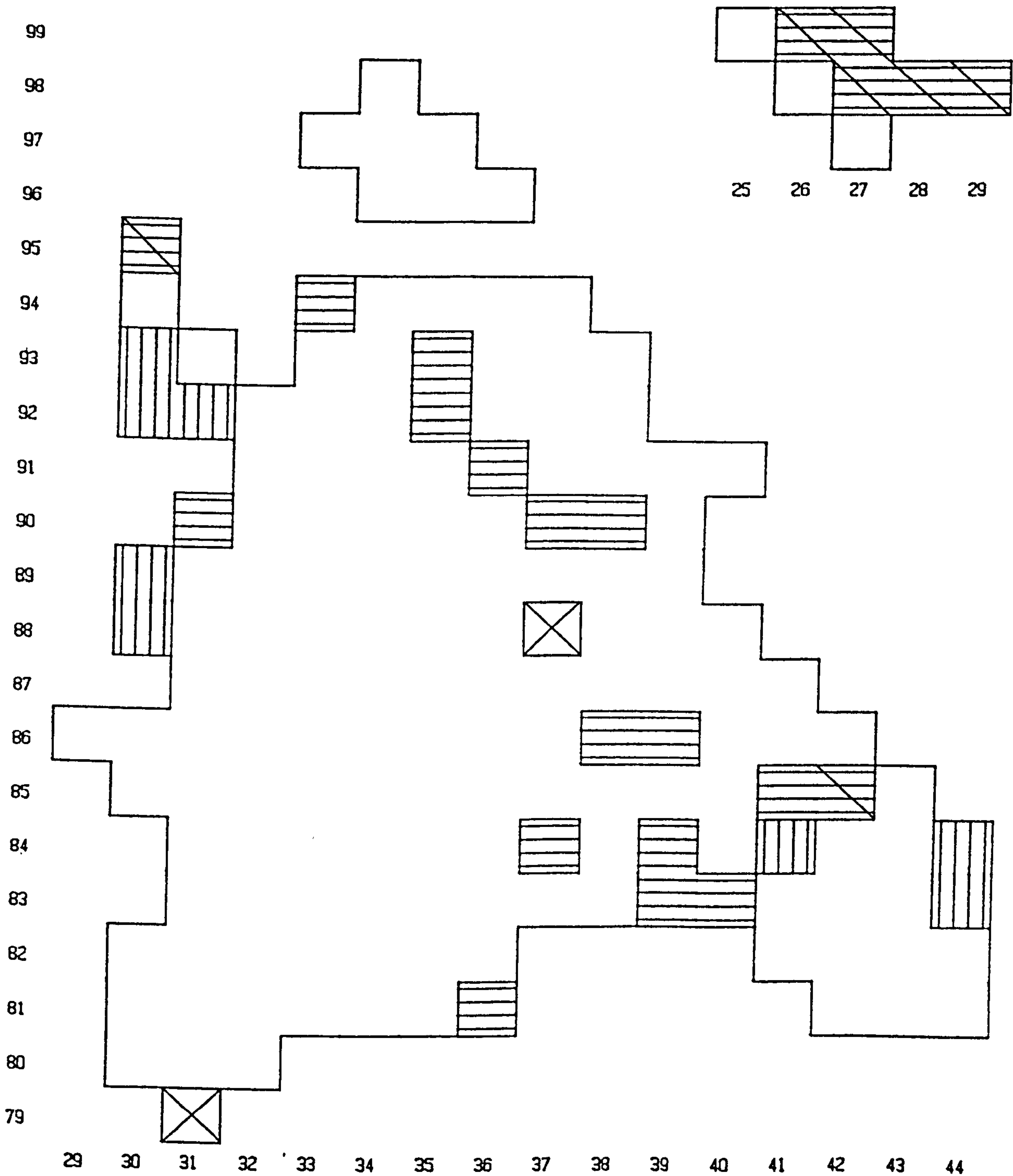


+1-2 S_y (3.47-6.93 minutes)

+2-3 S_y (6.93-10.40 minutes)



point lies $< +1S_y$ from WAIT/
CITYCENTRE regression line



A comparison of the positive residuals from the regression equations between WALK and WAIT and the socioeconomic variables indicates that for the most part points which have a poor service ($> +1\text{Sy}$) in terms of high walking time values do not have a poor service in terms of high waiting times and vice versa, the only exceptions being 3092 and 2799. A study of the positive residuals of TOTAL and OLD, YOUNG and NOCAR indicates that no point lies over $+1\text{Sy}$ from the regression lines which had not already been identified as having a poor service in terms of walking or waiting times. Thus if access to bus services is to be effectively improved, priority must be given either to the introduction of new routes or to the improvement of frequency depending on local conditions.

7. Conclusion

A model to describe the spatial variation in access to bus services in the Sheffield study area has been developed. The single most important variable in explaining present day variation was found to be of an historical nature; the correlation coefficients between the walking and waiting time values in 1972 and 1982 were 0.89 and 0.67 respectively. The incorporation of two spatial variables, the distance of sampling points from major roads and from the city centre, into the model improved the levels of explanation achieved. The three socioeconomic

variables investigated, the proportion of the elderly, the young and people in households without a car, were only weakly correlated with walking and waiting time values and their incorporation into the model did not significantly reduce the relative residuals. Incorporating all these variables into the model produced relative residuals of 0.196 for WALK, 0.520 for WAIT and 0.265 for TOTAL. The residuals from the regression equation between WAIT and WAIT72, ABROADS, CITYCENTRE, OLD, YOUNG and NOCAR indicate that large negative residuals occur in the SE of the study area, where the introduction of new bus services has taken place since 1972 to cater for the rapid residential development at Mosborough. The data for the 14 sampling points in the Mosborough ward were removed and the regression equations re-worked. The relative residuals for WALK, WAIT and TOTAL and the six independent variables were 0.058, 0.216 and 0.053 respectively which indicates that the regression model adequately describes the spatial variation in access to bus services in the Sheffield study area with the exception of Mosborough. Access to bus services in Mosborough is investigated in detail in the next chapter.

According to South Yorkshire's Structure Plan bus services are to be provided to benefit people in need, including the elderly, the young and people who lack access to a car. The weak correlations between the OLD, YOUNG and NOCAR variables and WALK

and WAIT indicate that present day bus services in Sheffield do not particularly benefit such groups. Changes in access to bus services between 1972 and 1982 also indicate that improvements to bus services since the formation of South Yorkshire County Council have not been particularly concentrated in areas with high proportions of people dependent on public transport. Thus the declared policy of providing bus services to benefit people in need has not been successfully implemented in Sheffield. A study of the positive residuals of the regression equations between WALK and WAIT and the three socioeconomic variables has enabled areas of the city where priority should be given to improving route density or service frequency in accordance with the aims of the South Yorkshire Structure Plan to be defined.

Walking time values (minutes)

205.

Waiting time values (minutes)

206.

Total time values (minutes)

207.